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FEATURES INDICATIVE OF PHYSIOGRAPHIC CONDITIONS PREVAILING AT THE TIME OF THE TRAP EXTRUSIONS IN NEW JERSEY

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The Watchung Mountains form prominent features in the topography of Northern New Jersey. On account of the great hardness and erosion-resisting qualities of the rocks composing them, they rise well above the surrounding shales and sandstones and add much to the beauty and picturesqueness of this portion of the state.

Their geological features and their relation to the adjacent strata have been the subject of study since the early years of the last century. Views regarding them have changed greatly. New facts have been brought to light and the interpretation of the observed conditions has changed with the advance of geological science. Gradually, however, a close agreement has been reached in the conclusions of various observers with regard to the major features of their structure and relations, and in brief form it may be said to be held that these three ridges are the remnants of three successive flows of lava which were poured out as great sheets over the surface of beds of sandstone, or similar material, which was in course of deposition at the time. After each flow the process of deposition of the sandstones was resumed until interrupted by the next flow. Later the whole series of sandstones and intercalated traps was slightly tilted so as to form a monocline with gentle western dips, and the edges were eroded and carried away. The trap sheets, on account of their resistant qualities, were

less degraded, so that now their projecting edges form the ridges of the Watchung Mountains.

In this article it is my purpose to describe certain facts of observation which have been met with in studying this region, especially that portion of it lying in the territory of the First Watchung trap from Paterson southward, and which may throw some additional light upon the relations of the traps and underlying sandstones and upon the general physiographic conditions which existed at the time of their formation. Quarrying operations of recent years have brought certain features to light which are of importance in their bearing upon this subject.

In order to lay a proper foundation for the facts which are about to be described and to show their significance, it is necessary to enter into some description of the underlying clastic formations.

THE CLASTICS

The lowest trap sheet (the First Watchung Trap) rests everywhere upon a series of siliceous stratified rocks. On account of the paucity of fossils contained in these associated strata and the somewhat uncertain position in the paleontological succession of the fossils which have been found, the exact horizon of these rocks is somewhat uncertain. They are generally regarded as being of Triassic Age, but it is preferable to use the indefinite term, "the Newark Formation," in referring to them, as is done by the United States Geological Survey, until more exact correlation can be established. In this article it is my intention to consider in detail only those members of the Newark Formation which are found in immediate association with the base of the First Watchung Trap, and to study these chiefly for the purpose of determining the conditions existing at the period when the trap sheet was poured forth. The rocks of the Newark Formation as a whole are of interest in this connection in forming general conclusions with regard to these conditions; but there is the possibility of undiscovered faults running through the series, which might throw altogether out of concordance the strata on the two sides of the break, and vitiate the value of the conclusions drawn. Therefore in endeavoring to arrive at a proper conception of the conditions immediately preceding the trap-flow, it is better to confine our studies to the terri-

tory closely adjacent to the trap itself, using in addition only such conclusions as apply to the Newark Formation as a whole.

At one time, before a detailed study of the region had been made and before the present advance of geology, a submarine origin was assigned to the Newark beds. Later the impossibility of their deposition under such conditions was perceived and it was suggested that they were laid down in an estuary or on the bed of a great river. This theory is still quite commonly held, but many later observers have come to the conclusion that they are almost wholly of continental origin. By this it is meant that they were laid down on land surfaces standing at some elevation above sea-level, on which bodies of standing water, such as lakes or pools, formed but a minor factor so far as sorting of material and deposition of sediments were involved. The conditions must be conceived to have been similar to those now present in the semi-arid inland basins of the West. The chief agencies of transportation and deposition were the general creep of waste material down slopes from disintegrating areas of older rocks in the high lands, the rush of torrential streams, the flow of rivers of more or less permanence, and the sweep of winds. In the lowest portions of the troughs of deposition there would naturally be shallow lakes, unless conditions of extreme aridity prevailed, and I will endeavor to show later that such lakes were probably present in the area under discussion at the time of the overflow of the trap.

In connection with the theory of a continental origin for these deposits we may quote W. M. Davis on the similar area in Connecticut:

> There is little or no direct evidence for marine deposition of the Connecticut Trias. There are no marine fossils yet found. The fish whose imprints occur plentifully in certain occasional strata of black shale are allied to fresh- or brackish-water forms. The prints of land plants and the tracks of land animals argue against the presence of the sea. The tidal currents that have been assumed to be necessary to carry the materials found in some of the coarser layers may be replaced by other agencies that can as well accomplish this result over the moderate distances here involved. If marine at all, the waters must have been littoral and shallow, and the bottom must have been frequently bared to the sun.[1]

These remarks are equally applicable to the New Jersey area.

Let us now examine the clastic deposits immediately underlying

[1] *Tenth Annual Report* U. S. Geological Survey, Part II, p. 32.

the Watchung traps and ascertain to what extent their structure bears out the theory of continental origin. We find that they form a monotonous series of shales, sandstones and conglomerates, composed mostly of quartz fragments. Sufficient oxide of iron is usually present to give a reddish, brownish, or purplish color to the whole. Feldspathic material is often visible, and the derivation of all these is plainly referable to the crystalline areas on the East or West. In addition to these we find in many of the coarser layers plentiful pebbles of limestone, up to six inches or more in diameter, whose source is obscure.

In observing carefully the succession of strata in this series one is at once impressed with the lack of continuance of the beds in any direction and the variation in the succession at different sections along the same horizon. Within a distance of a few hundred feet the character of the section may change markedly. This may be brought about in three ways.

1. A bed may gradually thin out and disappear. This is especially true of the sandstones.

2. The size of the fragmental material may alter in a pronounced manner, while the thickness of the stratum remains approximately the same. The proportion of pebbles in a bed of sandstone or even of shale may increase or diminish rapidly. This is generally brought about, however, by the intercalation of pebble beds in the sandstone layers, rather than by a general increase in the coarseness of all the material.

3. A given stratum may be cut sharply away, and different material abut against it.

All these variations are shown in the gorge of the Passaic River, a short distance below the falls at Paterson. Fig. 1 is from a sketch made just south of Ryle Avenue. Two very irregular bands of shale (*a* and *b*) cut sharply downward across the sandstone and pebble beds, and are overlain by strata differing from those in the same horizontal planes on the right. It appears evident that a water-course has cut its way through previously deposited strata, and the valley thus formed has later been filled by water-borne sediments or wind-blown sands until a level was again reached and a more orderly course of deposition was continued across it. The pot-hole at (*c*) filled with gravel, stones,

and shaley material, is instructive in this connection. Following these bluffs southward about 350 feet we come to the southern side of the same river-valley, as shown in Fig. 2. We find there, as we

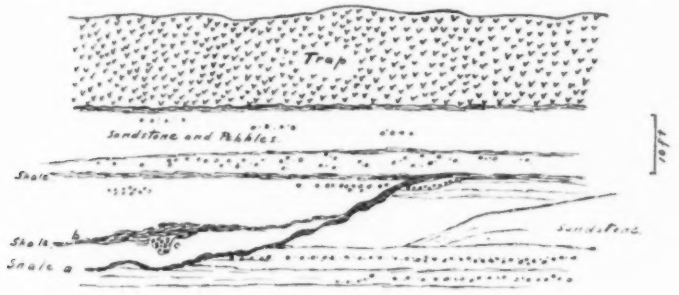


Fig. 1.

should expect, that while the line of the bank is shown by the same downward sweep of the strata, the succession of deposition is quite different from that shown in Fig. 1, indicating a desert stream which

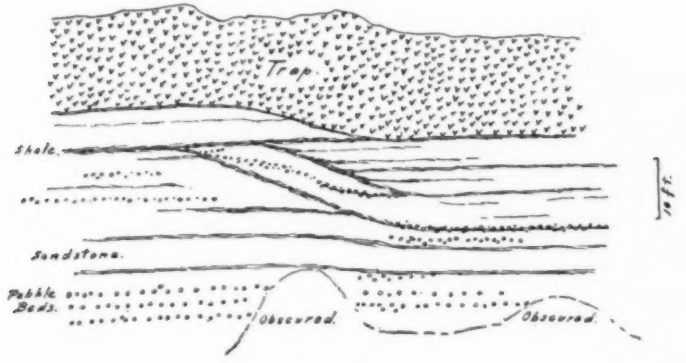


Fig. 2.

at times may have spread over the whole width of its course, and again dwindled to a rivulet or become dry. It is noticeable that the trap-sheet above also bends downward at this point, showing that a shallow depression still existed here when the lava stream covered the whole.

Another example of variations in strata is shown in Fig. 3, a section at Pope's old quarry, near Garret Rock. This is a sketch of the west face, north end of quarry. Marked variations of the strata show themselves along the quarry face, and the section shows no resemblance to any part of Fig. 1 or Fig. 2, though less than a mile distant and at the same horizon (just beneath the trap sheet).

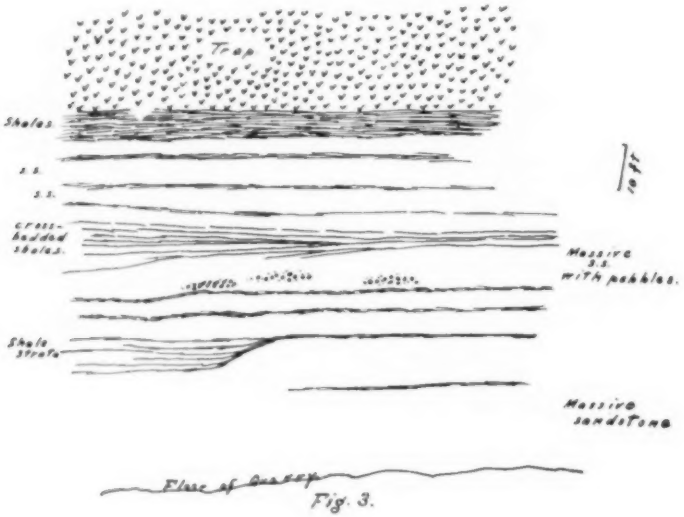


Fig. 3.

At Thomas' quarry at Albion Place there is an instance of the complete thinning-out and disappearance of a sandstone bed, probably five feet thick at its maximum. This is at the northern end. High up on the western wall a massive bed of sandstone has several feet of its upper part cut sharply away at one place, and shales abut against it.

These examples show the great tendency of the strata to vary in a large way, and are inconsistent with any form of marine deposition, or of any theory of deposition which does not take cognizance of sharp changes within small areas. When we take up the consideration of smaller details of structure we are met again with proofs of this same tendency to variation, as is shown by a study of the smaller features of the shale, sandstone, and conglomerate beds.

THE SHALES

These are well described by the term "ferruginous silicilutytes" of Professor Grabau's classification; that is, they are finely-comminuted siliceous material, strongly impregnated with oxide of iron. Their laminations may be paper-like in thinness but are generally coarser. On exposure to the weather they break up into a multitude of crumbly fragments. Mica scales are very plentiful. The surfaces of the laminae frequently show a multitude of irregular markings—grooves, pits, curved lines, lumps, smooth patches of irregular shape, etc., not all of which can be deciphered with any certainty. Many, however, can be identified. Mud-cracks, rain-pits, and worm-grooves are frequent. Rill-marks are sometimes found. At times films of impalpable sediment are found in the depressions in the lumpy surfaces of certain sandstone layers, which, in their delicate markings, suggest irresistibly the frothy scum left in hollows after a rain. Again thin curled layers of shale appear plentifully in the midst of sandstone. The effect is precisely that which would be produced by a layer of mud, drying and curling at the edges, being buried by a deposit of wind-blown sand. The layers of mud are too fragile to permit the supposition that the sand was carried by currents of water. Other examples show plentiful flakes of shale mixed with sand, the occurrence being apparently due to a mixture of material produced by the wind. I have seen wave-marks in the shales and have found them also in the finer sandstones. In the latter too I have found one very distinct print of an apparently three-toed reptile. The impression is a trifle over an inch in width and on one side is an irregular, curved groove, probably made by the animal's tail. In the fine shales there are many impressions which suggest the marks which would be made by living creatures moving about in soft mud. They are too uncertain, however, to offer more than a suggestion. In other localities, as in the Connecticut valley and other parts of New Jersey, many reptile trails have been found, but those spoken of here were found in the territory under discussion in material taken from a short distance below the trap sheet, and serve as an index of conditions just preceding the flow.

These shales are to be regarded as muds deposited in lakes, rivers, or pools. The markings described owe their preservation to the

retreat of the waters and the baking of the mud under a hot sun. That arid conditions prevailed is indicated also by the frequent presence of sharply defined pieces of shale in the pebble beds. During long exposure the iron-impregnated mud must have hardened to such a degree as not to be ground up and destroyed by a succeeding rush of torrential waters.

THE SANDSTONES

These are ferruginous silicarenytes—siliceous sands, colored by oxide of iron. In places they form extremely massive beds in the series, up to 25 or 30 feet in thickness, with hardly a line of parting. Beds of this kind are made up of rather coarse quartz fragments, rounded or subangular, mixed with a little decomposed feldspar, and frequently show no hint of stratification on either fresh or weathered surfaces. The finer sandstones carry much mica and are generally better stratified. A little cross-bedding has been observed, the direction of the lines differing by a slight angle.

Fig. 4

The sandstone strata may contain anywhere in their mass individual pebbles or small beds of pebbles of irregular shape and extent. Fig. 4 shows a characteristic pebble bed on the west side of Thomas' quarry. Pebbles are up to one-half inch or more in diameter. Below is even-grained sandstone separated by a sharp line from the pebbles. Above, the gravel grades into sandstone. Fig. 5 represents the structure of a gravel bed a few hundred feet north of the D. L. & W. R. R. station at Paterson. On the left side the dividing line between gravel beds and sandstone cuts sharply downward across the sandstone layer. On the right there is a grading of pebbles into sand. A rough stratification is apparent in the pebbles. Fig. 6, from Pope's quarry, illustrates a somewhat different feature. The intercalated bed is here mostly shale, in the midst of a massive sandstone.

Fig. 5

Fig. 6.

These are by no means isolated occurrences, but are repeated in a similar fashion in innumerable exposures. The obvious explanation is that they represent the channels of small streams which cut across the face of the country. The sandstones in which they occur I would refer to an aeolian origin, and believe them to have formed the surface of the ground at the time the streams cut their channels. By this I would not be understood to imply that water played no part in the transportation of the sand grains from their original homes in the crystallines. They may have been picked up and laid down repeatedly, now by wind and again by water, before reaching their final resting place, and it would be impossible to draw a sharp line and say that here the work of water ceased and here the work of the wind began. Their final attitude, however, is to be attributed chiefly to the action of the wind. The fact of the subaerial accumulation of the great masses of sandstone should be emphasized, for their freedom from moisture at the time of the trap flow has an important bearing upon certain structural features of the trap.

At Little Falls, a few miles west of Paterson, a bed of sandstone lying about fifteen feet below the second Watchung sheet, carries abundant plant impressions. The remains of woody stems are found which have been converted into coal, and twigs and leaves have also left their impressions in the stone. From the completeness of the forms preserved the trees were evidently not carried to this point from a distance and I am inclined to believe that this is actually the site upon which they grew. Although not in the area under discussion, this occurrence is interesting as indicating the continuation of continental conditions up to the time that the second flow of trap spread over the region.

THE CONGLOMERATES

Everywhere throughout the sandstone strata pebble beds similar to those described are of frequent occurrence. Even the shales may contain locally a large amount of gravel. In addition to these, heavy beds of coarse conglomerate are sometimes seen, though they are not as frequent as the sandstones and shales. They were exposed a number of years ago a little to the southeast of the Great Notch in a trench dug for a water-supply system, and at the present time are especially well seen in the sandstone quarry in the gorge of the Passaic,

on the eastern side of the river. The conglomerates here carry quantities of shale mixed with the gravel. The old streams, of which these are the beds, evidently deposited at times quantities of mud. As the waters ceased flowing the mud was dried and baked till it became well hardened. When the next rush of waters came some of the strata of hardened mud withstood the force of the stream, but others were broken up and the pieces mixed with the pebbles and swept along with the current. From the recurrence of the phenomena this must have happened time and again.

The pebbles of the beds are mostly quartz, sometimes only slightly rounded. Limestone is also of frequent occurrence.[1] Often weathered surfaces of the conglomerate show rounded cavities from which limestone pebbles have been dissolved, and the general porosity of the beds may be partly due to the solution of smaller lime grains. The presence of these limestone pebbles indicates a not distant source, but nothing from which they could have been derived is to be found for many miles. The original strata were either totally broken up and carried away or, more probably, were buried beneath later deposits.

It is to be noted that the pebbles are all of moderate size, rarely more than six inches in diameter. No bowlder masses, like those which are common in river channels, ancient and modern, in regions of rugged relief, are to be found here. The trough of depression, in which deposition was proceeding, had been filled so that the surface of the buried valley was now almost a level plain, on which the rush of waters, even from torrential streams, soon lost its force.

From the evidence of the rocks themselves at the base of the First Watchung Trap we are able to picture, with a fair amount of certainty, the character of the region and the conditions of the deposition of strata preceding the period of the lava flow. We see on the east and the west chains of hills of moderate relief, composed of the old crystalline rocks, whose surfaces gradually disintegrated under the effects of the weather, and the detritus from which was carried down the slopes and spread over the intervening valley. The climate was arid,

[1] In a couple of pebbles of decomposed limestone which I found in these conglomerates there were abundant fossils. Crinoid segments were very numerous, and bryozoans were abundant. There was also a fragment which may have been the pygidium of a trilobite.

and during the long periods of drought the streams dwindled away or sank into the sands. At times, however, torrential storms or cloudbursts occurred and the sudden rush of waters carried heavy loads of waste material before them. In the dry periods strong winds played an important part. They gathered up every exposed grain of moderate size from the higher ground, and swept it into the valley and spread it out in accumulations which reached great thickness.

The floor of the valley was almost flat, or at most had a gentle slope away from the mountains toward the axis. In the lower-lying portions lay one or more shallow lakes, which in periods of comparatively large rainfall spread over wide expanses, and in dry periods contracted within narrow limits.

THE LAVA FLOW

Over such a region as we have pictured a great lava flow was suddenly poured forth. The points at which extrusion took place are uncertain. There seem to have been no preliminary phenomena such as often precede lava flows. No deposits of tuff or other ejectamenta, indicative of explosive violence, are found in this region. The lava seems to have quietly welled forth and, as we shall see later, spread out in a thick sheet in a flow which was practically continuous.

From whatever point the flow may have entered the region its natural course would be along the trough of the valley. The shallow inequalities which existed in the surface offered no serious obstacle to it; the fluid lava filled them and passed on. Such small bodies of water as were encountered were perhaps quickly turned to vapor and driven off. Nevertheless the lakes have left their record upon the molten rock, and though in places the writing has become dim with the lapse of ages, it has proved so nearly indestructible that it can still be deciphered, and the site of the lake beds, and hence the line of central depression of the valley, can be determined with a fair degree of confidence. If we are not able to do this throughout the area, it is because the field has not yet been thoroughly studied with this object in view, or because the structure of the trap is not sufficiently revealed in the surface exposures.

The process of reasoning is as follows: Where the lava covered arid soil it was practically unaffected by water. The air and the

trace of water contained in the interstices of the ground would be expanded by the heat, and having no other escape would force themselves into the molten lava and render it vesicular for a short distance above the contact, but the great mass of lava would be left dense and unaltered. At the surface of the sheet the escape of occluded gases might also produce a slightly porous structure. But where the lava poured over lake beds the case was different. The standing water was probably not of sufficient volume to produce much effect, but the underlying strata were thoroughly saturated. The heat of the lava penetrated downward slowly but irresistibly, and the water was vaporized. If there had been no means of escape, the pressure would have gone on accumulating until it became enormous, but before this the vapor began to push itself up through the over-lying lava, and thus found vent. It continued thus to force its way long after the lava congealed, and finally the temperature dropped to such a degree that currents of heated water replaced the steam. The effects produced constitute the record left and will be described in detail.

Let us first, however, examine the structure of the trap in its less affected portions. The gorge of the Passaic in the vicinity of Figs. 1 and 2 offers good opportunities for this. It is seen that the contact is practically conformable with the stratification of the underlying sandstone series, but there are slight irregularities, and at the point where Fig. 2 was sketched the trap drops about six feet. For a short distance above the contact, that is, from a few inches up to four or five feet, the trap is vesicular. Above this it is firm and dense to the top of the cliff. At Garret Rock there is another good exposure of the contact where the D. L. & W. R. R. rounds the point of the mountain. The contact is perfectly sharp, but slightly irregular. There is no mixture of the trap and sandstone. The vesicularity of the trap extends about three feet up and the sandstone also shows small passages through which gases were forced. Fig. 7 shows a typical example of the contact here. In some places the trap is so welded to the sandstone that the same hand specimen will show both.

Fig. 7

At the trap quarry southwest of Albion Place there are certain features of interest. At the contact there is a mixture of vesicular,

decomposed trap, and lumps of hardened mud. The whole is much affected by weathering, but it is easy to distinguish between the igneous and sedimentary material. This mixture forms an irregular band about six inches in width. Below is red shale, not perceptibly altered, extending downward for several feet. Above the mixed band, the trap is vesicular for a few inches, and passes upward into fine-grained, dense rock. The impression produced is that the first thin stream of advancing lava flowed over a bed of rather damp mud and became mixed with it, and that this in turn was soon covered by later streams.

In this quarry for one hundred feet or so along the quarry face, about six feet above the contact, there is a band of trap, two or three feet in width, having the structure shown in Fig. 8. The lines of the sketch represent cracks from one-half inch wide down to a mere seam, which extend approximately horizontally along the cliff face and back into the rock, and permit it to be separated easily into slabs. The cracks are filled with a loose, granular material, generally of a dark color, but showing calcite grains in places. This same slab-like or platy structure can be observed as of frequent occurrence in the more massive portions of the trap sheet in various localities, though seldom so well developed as here. It is a fair inference that these plates represent rivulets of lava, and that the chilled surfaces have been more easily weathered. The advance of the lava flow should not be pictured as similar to that of a sheet of water. On account of viscosity and partial congelation, the spreading out of a sheet of even the most fluid lava is quite a different process. We should picture the advance of this Watchung sheet as similar to the form of the Hawaiian lava flows described by Major Dutton:

Fig. 8.

> When these lavas are discharged they come up out of the ground in enormous volumes, are intensely heated, and are very liquid. . . . . As they become cooler they become more viscous. The cooling takes place upon the surface of the mass while the interior still remains hot and preserves a viscous liquidity. The superficial crust of cooled lava undergoes rupture at numberless points, and little rivulets of lava are shot out under pressure. Preserving their liquidity for a short time, they spread out very thin and are quickly cooled, forming pahoehoe. Scarcely is one of these little offshoots of lava cooled when it is overflowed by another and similar one, and this process is repeated over and over again. In a

word pahoehoe is formed by small offshoots of very hot and highly liquid lava from the main stream, driven out laterally or in advance of it in a succession of small belches. These spread out very thin, cool quickly, and attain a stable form before they are covered by succeeding belches of the same sort.[1]

Above the reticulated strip described comes fifteen feet of nearly massive trap with few joints or planes of separation, and above this, along an irregular line, there is a blocky variety of considerable thickness. Except for the narrow band of vesicular trap on the contact the texture of the whole mass is firm and dense and the rock is of flint-like hardness.

We may continue southward for several miles along the cliffs marking the eastern face of the mountain, and find almost identical conditions everywhere. The base of the trap sheet shows slight irregularities but is practically conformable with the bedding of the sandstones and shales. For a short distance above it is apt to be somewhat porous, but the great upper mass is perfectly dense.

Evidence of the existence of a lake bed, covered by the lava flow.— Let us now follow the D. L. & W. R. R. westward from Garret Rock to the West Paterson trap quarry. Garret Rock is a bold cliff marking the eastward scarp of the mountain, and from here the railroad makes a section almost at right angles to the line of the ridge. About three thousand feet from the rock it passes the quarry mentioned, which is in the very midst of the trap area. The quarry has been famous to mineralogists for years for the specimens of zeolites and associated minerals which have been obtained from it. It is only within about a year, however, that operations have proceeded so far that the geological conditions have become plain and the whole story revealed so that it can be easily read. The section is so perfect, and the rock and its minerals are so fresh and unaltered that a careful study of the exposure should be made. We shall find here the explanation of features occurring elsewhere, which by themselves might convey little meaning.

The first observation which will probably be made is that here in the midst of the trap area the bottom of the quarry shows a floor of hardened red mud rising from the west toward the east. On this the trap rests. Along the contact for a width of ten feet or more the

[1] *Fourth Annual Report*, U. S. Geological Survey, pp. 95, 96.

trap and mud show evidences of having experienced the most violent agitation. The two are mixed and kneaded in a manner so involved that it can hardly be imagined. The mud has boiled through and through the seething body of lava until particles of mud of every size from minute specks to large masses have become incorporated in the pasty flow. Both lava and mud are full of blow holes, steam vents, and other forms of irregular pipes and cavities which attest the violent escape of gases.

Above this confused mixture the lava is generally found to show a transition to a purer condition. It is still thoroughly vesicular for

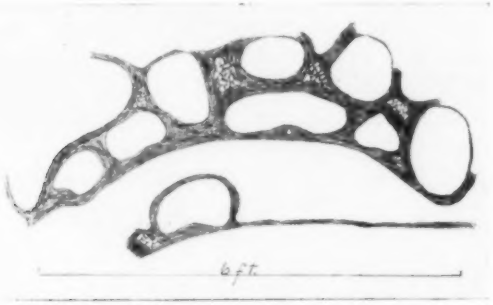


FIG. 9

several feet, but less mud is found in it as we go upward. Still higher no mud whatever is found, and the overlying mass of lava, probably nearly seventy-five feet in thickness to the surface, is purely igneous rock. The structure of this, however, is very different from the close-textured rock which we found along the eastern border of the trap sheet; and, in its way, the evidence of the action of escaping gases and heated waters is as perfect as in the underlying portions. Amygdules are still frequent, but the more characteristic appearance is the bowlder-like structure shown in Fig. 9. The bowlders are of dense trap, with crusts of dark glass. Vugs of mineral lie between, and it is in these vugs that the crystallized zeolites are found.

This structure is common throughout the whole quarry. Even the masses of trap which do not show the glassy crusts or the vugs are so seamed with fissures as to be easily broken apart. Toward

the surface of the ground this structure is not so evident. This is mostly due, no doubt, to the leaching-out of the secondary minerals, but the impression is left that in its original occurrence it may not have been so well developed in the upper layers.

The course of events which gave rise to these features is to be explained as follows: Before the lava flow occurred this site was occupied by a shallow body of water with a muddy bottom. When the first thin flow of intensely heated igneous rock plunged into it, the violent agitation resulted in a thorough mixture of the two. At short intervals further flows added to the depth of the mass. The successive spurts and tongues of fused material burst forth everywhere. Chilled almost at once by the steam pouring around them, they built up a structure of bowlder-like forms. The original body of water was quickly driven off, but that contained in the saturated strata beneath was changed to steam and rushed up through the mass. Some of it found its way into and through the fused material, but the greater part worked its way around and among the bowlders, with the result of quickly cooling the crusts, producing a glassy texture and a multitude of cracks. The evidence of these effects throughout the seventy or eighty feet to the surface indicates that at least this depth of lava had reached its position while the action was still continuing, though it does not follow that there may not have been intervals during which the flow of lava ceased.

Further than the physical effects of chilling the lava and producing the crusts and cracks, the steam seems to have had little result. In places the inner surfaces of the blow-holes have no lining of minerals but appear entirely unaltered. In another locality, which will be described later, many of the steam vents were blown full of sand or dust and this frequently lies up against the chilled glass, without any indication of alteration in the latter. Later, after a considerable interval of time, the mass of lava cooled to such a degree that the underlying reservoirs began to supply a mixture of water with the steam, and finally merely heated waters passed up through the vents, and with these the crystallizing action and formation of minerals began. The lava had been so thoroughly seamed and cracked that it could not have offered much obstruction to the flow of these waters, and it does not seem that they could have been at any time under a

pressure which would greatly raise their boiling point. Rather must we suppose that the principal mineralizing effects were due to waters having a temperature but little above 100° C.

Further evidence of a relatively unobstructed and rapid circulation of water is supplied in the fact that frequently the transparent crystals lining the vugs show inclusions of dark sediment, or again the crust of perfectly formed crystals is covered with a deposit of the same sedimentary material.

The minerals produced are largely due to the action of these hot waters upon the glassy crusts of rapidly chilled trap. The muds themselves show practically no alteration except hardening, and the elements of the minerals are those of the igneous rock, with water added. In fact the zeolites seem to be the direct result of the addition of water of crystallization to the albite and anorthite mixtures of the feldspars and result from a crystallization of previously existing silicate material by a slight modification of its composition. The presence of datolite and apophyllite—compounds carrying boron and fluorine—indicates that the elimination of magmatic vapors from the igneous material was still in progress during the process of formation of the secondary minerals. Such emanations may have been powerful agents in conveying to the channels of circulation material derived from the magma, and in the rearrangement of the various elements present.

All stages of transition in the alteration of the trap and the formation of minerals from it are common. Frequently we find a breccia with angular fragments of trap as nuclei and crystalline minerals for a filling. The most perfect crystals, however, form linings to the cavities between the bowlders. I believe there is evidence of a definite sequence in the formation of the minerals but there are difficulties in determining it in many cases. Apparently, however, it is as follows: First, a dark green, chloritic mineral, followed by prehnite, datolite, and pectolite; then the zeolites, analcite, laumontite, chabazite, natrolite, heulandite and stilbite; ending with apophyllite and thaumasite. Quartz and calcite are very common but seem to have been deposited at several stages and cannot be assigned a definite position in the series. The only metallic minerals observed are chalcopyrite and hematite. Small grains of these, sometimes well crys-

tallized, are common, but like quartz and calcite, they cannot be given a definite place in the order of deposition.

The structure which I have described changes toward the surface. It may not have been so well developed in the upper layers, and weathering has obscured the effects. So far have the changes proceeded at this point that the outcrops of rock just above the quarry have to be examined very carefully before any difference in structure can be noted between these rocks and the ordinary firm-textured trap. A wide area of surface surrounding this point plainly shows a survival of the structural differences described, but immediately back of the quarry they are almost gone, though so well developed in the rock beneath. This point should be noted, for in following on the surface

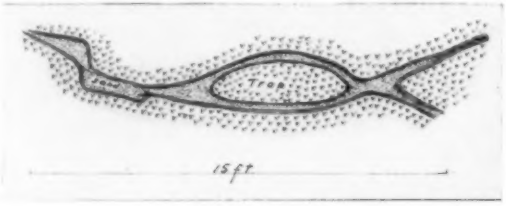


FIG. 10

the area which was underlain by the lake we find occasionally areas of dense-textured rock, lacking practically all evidence of being different from that which overflowed the arid country, and we should perceive that the presence of surface rock of this nature does not necessarily imply the lack of the characteristic structure beneath. In the areas which I have explored, however, the altered rock has been so frequently found where it has been expected, and where it should have been developed if the lake had the form assumed from the position of the few well-developed exposures which I first noted and on which I based the theory of its existence, that its general form and position can be predicated with fair confidence.

The features which best survive the effects of weathering are the extremely vesicular or sponge-like facies of the lower layers near the contact, and the smooth, rounded, bowldery forms with brecciated crusts of the upper parts. Of the secondary minerals few survive prolonged weathering, except quartz and prehnite and occasionally

calcite, but the irregular cavities from which they have been dissolved have frequently been noted.

The surface areas on which I found these structures in the immediate vicinity are indicated on the map.

Let us now go southward about three miles to an old trap quarry near the Great Notch, formerly worked by Francisco Brothers.

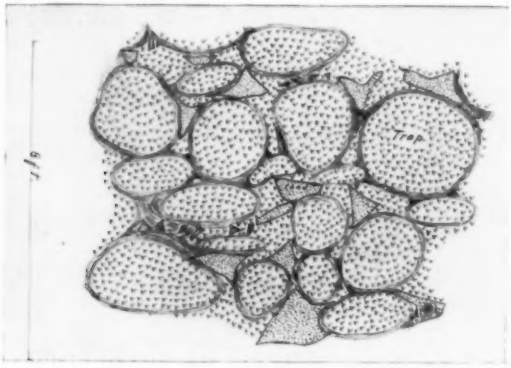
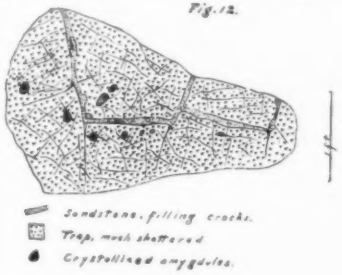


FIG. 11

Unfortunately no work has been going on here for several years so that the features to which I wish to call especial attention can now be seen at a few points only, though formerly visible over a good part of the quarry. Fig. 10 is from a sketch of the south side of the quarry made in 1902, and Fig. 11 is of the east side made at the same time. The bowlder-forms noted in the West Paterson quarry were well developed and the crystal vugs were also present; but a new feature to be noted is what at first sight appears to be a breccia of sharply defined, angular blocks of sandstone, ranging up to a foot in diameter, lying in the midst of the trap. Their presence in a surface flow of lava might be extremely puzzling until some such occurrence as that shown in Fig. 12 is noted. From a



study of this and of the other occurrences it is seen that the blocks of sandstone are in reality made up of finely divided material caught up from the bottom of the lake and carried to their present position in the form of dust by the blast of steam. Later they were consolidated by the deposition of secondary

FIG. 13

minerals, but the amount of the latter is so small as not to be perceived at a casual glance. So fine was the dust that it penetrated the most minute crevices and at times its presence can be detected only with a lens. Fig. 13 shows a small block of trap with sand inclusions, drawn in careful detail, and Fig. 14 is another portion of the same block as Fig. 13, showing dust-lined amygdules, later

filled with zeolites. It should be noted that the surface trap at this quarry is of the dense variety for a thickness of several feet and gives no hint of the structure underneath. A short distance west of this point, just below the main line of the N. Y. and Greenwood Lake R. R. is the entrance to a water-supply tunnel, which was driven under the mountain a number of years ago. It entered trap on the western side and came out in the sandstone country on the east, and

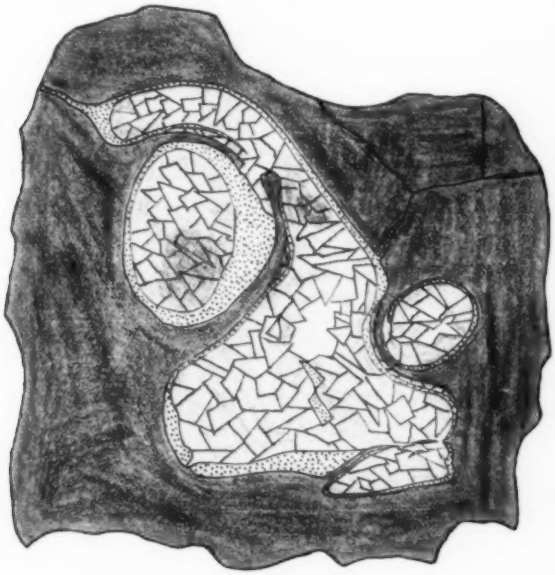


FIG. 14

in its course passed almost directly beneath the Francisco quarry just described, but at a much lower level. At the time that work was in progress much of the material brought out and thrown on the dump was of the characteristic structure which we recognize as being associated with the portion of the lava flow which plunged into the old lake. Glassy crusts, crystal-lined vugs, and sandstone inclusions were all common.

The two localities described, the one at West Paterson and the other at Great Notch, give us the general line of the lake valley and

show us the changes in the trap by which we can recognize its position. I will now take up some of the typical exposures and describe any details which may seem of importance. The most northerly point at which I have found evidence of the existence of the lake is at the corner of Union Ave. and Marion St. in Paterson. There is a small outcrop of trap here, showing bowlder forms and glassy crusts, stained with copper. About half a block south is the site of Hoxsey's quarry, which many years ago was a famous hunting-ground for mineral collectors, and specimens from which are found in cabinets throughout the country. The hill of trap which formed the quarry was leveled off years ago and work was abandoned. A large part of the quarry ground is now built up with houses and nearly all trace of it is gone. When I was familiar with it the form of its structure bore little significance to me, but I remember the general details and believe the structure was almost a duplicate of that now showing in the upper portions of the West Paterson quarry. In one place the floor of the quarry showed calcite-impregnated, amygdular trap, but work was not carried below this. I do not recall the presence of sandstone inclusions, but upon a recent visit to the locality (September, 1907) I was lucky enough to find a little work going on in Kearney St., apparently for a sewer connection, which showed perfectly the crusted bowlder-forms and the vugs and also sandstone inclusions.

Southerly from here is an exposure just east of the reservoir on the hill near the Soldiers' Monument. The outcrop is small but the characteristic features are well developed. This exposure is only a few hundred feet west of the cliffs where Figs. 1 and 2 were sketched and we are now able to appreciate the full significance of the valley shown in these sketches. We see that a river at one time entered the lake at this point, but its valley had been nearly filled and its course almost obliterated until only a shallow depression remained at the time of the trap flow. Its bed was dry, as is shown by the slight degree of vesicularity of the trap at the contact and the close texture above, whereas, over the lake bed the water-soaked muds wrought changes in the trap to a much higher level.

Going a little farther south we come to a small abandoned quarry just across the road from the Water Works Pumping Station. We may note the bowlder-forms here with which we have become familiar

and there is another feature of especial interest. The slaggy, wrinkled crust of one of the flows is finely exposed in two or three places. It projects as an inclined shelf, one or two feet wide and fifteen or eighteen feet long, from under later trap, but at only two or three places on this shelf is the structure perfectly developed. The wrinkled surface is shown in Fig. 15. It appears to be a crust one-half to two inches thick, over another flow which also shows a wrinkled surface in one place. Although somewhat weathered the original rock was plainly of a close, glassy texture. No vesicles are visible. The wrinkles are plentiful, forming curved grooves one-fourth to one-half inch deep. The direction of all of them points to a flow northward at this point, and though we must not lay too much stress upon this, a northward flow is perfectly consistent with the shape of the valley. This crust does not of course represent a part of the final surface of the lava flow. It is merely the crust of one of the small sheets, spurted forth under pressure, and soon covered by other portions of the flow. The innumerable bowlder-crusts to be found throughout the area which we are studying are practically the same thing, but in few cases was the wrinkled surface preserved so perfectly as in this example.

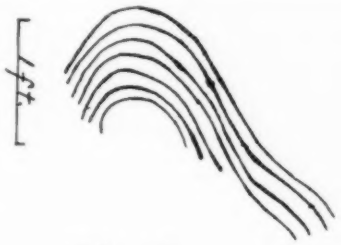


Fig. 15.

At the Falls the rocks on both sides of the river at the brink of the chasm show many irregular vug holes and in places crystals can be seen. We are here, however, far above the base of the sheet and the exposure is not a typical one. Farther south there is an occurrence on the Little Falls turnpike, showing the characteristic structure. The most noteworthy feature is the recurrence here of the wrinkled crust of one of the bowlder masses, showing as a slight projection.

Next comes the West Paterson quarry already described in detail. I have found in this vicinity evidences of the lake valley over a large surface area but have not yet had the opportunity to explore the vicinity in sufficient detail to fix definitely the limits of the area covered by the lake.

Going southward from this point along the mountain road there are positive evidences at many places, as indicated on the map. I have no doubt that with some search other characteristic exposures can be found in this vicinity.

Southwest of the mountain reservoir there is another large area shown. Along the road and in adjacent fields the trap is very vesicular. Plowed fields are filled with the honeycombed fragments and some is plainly in place. A little to the westward the stone walls are built of the crusted bowlders and rock of this structure is also found in place.

South of Great Notch the occurrences in the pipe-line tunnel and in the old quarry of Francisco Brothers have been described. Francisco's new quarry also shows it well at the southern end.

About a half-mile south of Great Notch station is the reservoir of the Newark water department. The work here was done in 1902 and at that time the progress of the work showed the character of the trap underlying the valley. From the gate-house a deep trench was excavated North and South as a foundation for the dam. In this the trap was very porous and vesicular for many hundred feet. From the surface to a depth of twenty feet or so the trench showed bowlder-drift. For probably forty feet below this the trench was in rock, very vesicular, with abundant minerals. Stilbite, chabazite, heulandite, prehnite, calcite, and quartz were recognized. From the gate-house other trenches running east and west showed vesicular trap for several hundred feet. A little to the north the quarry which was opened up for the purpose of obtaining rock for the concrete of the dam shows the bowlder-structure and alongside the road running eastward in front of the dam the rock is honeycombed. These last two exposures are still in evidence, but that in the trenches is now covered with tons of earth and masonry, and the only indications of the rock taken out are the bowlders piled in the road embankment.

I have not traced the prolongation of the valley south of this point. At Upper Montclair the trap quarry of Osborne and Marsellis shows a set of phenomena which probably has some connection with it, but the exact relations are not certain. The contact of trap and sandstone is seen to be very ragged. Angular blocks of sandstone project upward a distance of eighteen inches or two feet into the trap

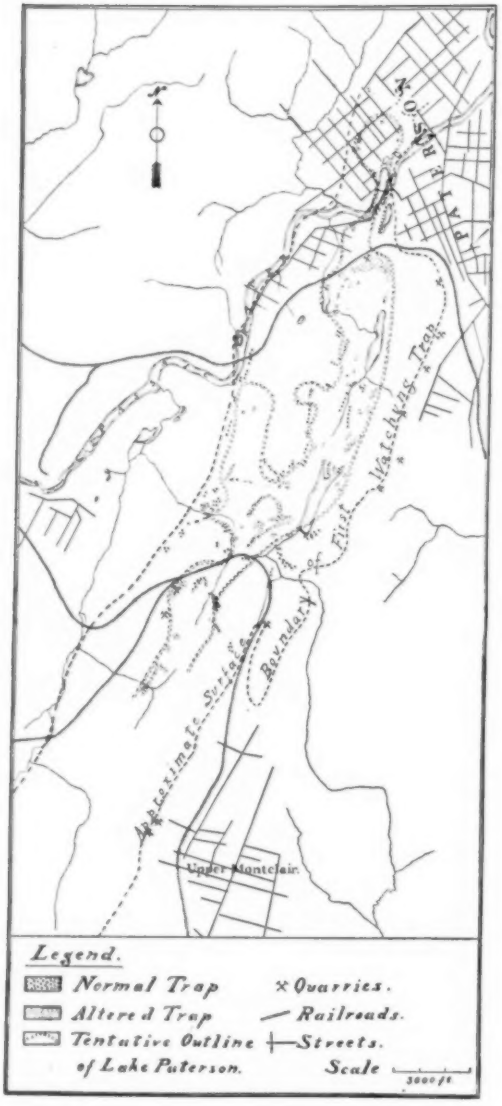
in many places. Above the contact much of the trap is vesicular, but in places dense trap comes down to the contact. The vesicular trap gives on weathering a brownish, pulverulent, tuff-like material, but I do not think that true tuff is present. Where not weathered it contains many seams and vugs of crystals. The dense trap is sometimes separated quite abruptly from the vesicular form and in other places there is a transition from one to the other.

There was evidently considerable agitation here at the time of the trap flow, but it does not appear to have been so violent as in the cases previously described. The position of this quarry is on the eastern edge of the trap sheet, somewhat removed from the line of direction of the lake valley, so far as determined. I should consider that this marked a spot of marshy ground in the general area of the lake basins, rather than a large body of water. Professor Kemp (in a personal communication) reports the discovery of reptile trails in the shales underlying the trap at this quarry.

A reference to the accompanying map will show many other localities in which typical exposures have been found. In most of these cases the crusted bowlders are the most prominent features to be observed in the structure of the rock. In a few cases I have indicated on the map outcrops of normal, dense trap. These are only shown where they have some significance in defining the limits of the lake area.

FAULTS

An explanation of the appearance of the shales beneath the trap sheet at the West Paterson quarry in the midst of the trap area is required. Along the eastern scarp of the ridge the sandstone series is found to have everywhere a gentle westerly dip, averaging six or seven degrees, as it disappears beneath the trap. Assuming that this dip continued from Garret Rock westward to the quarry, the base of the trap sheet should lie several hundred feet beneath the surface at this point. To explain the reappearance of the sandstone then we must suppose either that there has been a sudden reversal in the direction of the dip or that it has been brought up by faulting. There is no evidence of a reversal of dip and its existence would be contrary to the general monoclinal


Watchung Trap
First
Approximate Sutro Boundary
Upper Montclair
Legend.
Normal Trap
Altered Trap
Tentative Outline of Lake Paterson.
× Quarries.
Railroads.
Streets.
Scale
3000 ft.

structure of the region. There are, however, excellent reasons for supposing that a series of northerly and southerly faults runs through the country.

A little west of Garret Rock there is a very evident displacement, described and figured by Davis in his paper on the "Triassic Traps and Sandstones," and referred to by Darton,[1] who figures a displacement of about seventy feet, with downthrow on the eastern side, and with this allowance calculates a thickness of seven hundred feet for the trap sheet along this section. On this supposition the underlying shales should lie not less than two hundred feet beneath the surface at the West Paterson quarry. As they are brought up again at this point a displacement of something like two hundred feet by faulting is shown to have occurred, in addition to the seventy-foot throw referred to by Darton. In the quarry itself there are many nearly vertical planes of cleavage, running from top to bottom of the quarry and having a direction nearly north and south. Over much of the country covered by the map there is a prominently developed set of cleavage planes having a general northerly and southerly direction (N. 0 E. to N. 30 E). Frequently where a little quarrying has been done they appear as innumerable sharply defined breaks in the quarry walls. Near the road which runs through the gap of the Great Notch a series of pinnacles on the northern side indicates a faulted structure. This same series of faults continued southward follows the line of valley along which the N. Y. & G. L. R. R. has been built from the station at Montclair Heights northward, and apparently has resulted in the two parallel crests of the ridge here. The faults are well shown in the large quarry near the railroad line in this inner valley and the movements have resulted in the formation of slickensides and gouge matter. There is reason to believe from the evidence at hand that a multitude of displacements of slight throw, and a few well-developed faults of greater throw, all having a northerly and southerly course, have affected the country. The appearance of the underlying lake bottom at West Paterson subtracts two hundred feet from Darton's estimate, and possible displacements to the west of this are likely to reduce the figures still more.

[1] *Bulletin 67*, U. S. Geological Survey, "The Relations of the Traps of the Newark System in the New Jersey Region," p. 23.

RÉSUMÉ

We have seen that the series of clastic rocks of the Newark Formation underlying the First Watchung Trap was deposited as surface accumulations in a semi-desert area, mostly under subaerial conditions, in which the wind played an important part. Most of the material from which it was derived is plainly traceable to the old crystallines on the borders of the basin. Either the original floor of the basin on which accumulation began was almost a plain, or accumulation had proceeded to such a degree that minor features of relief had been buried by it, resulting in a surface with only gentle slopes at the period immediately preceding the extrusion of the trap sheet. The usual topographical features of such a surface, in the nature of shallow valleys and stream channels, were present, and we must suppose that the naturally heavier accumulation of detrital material along the bases of the bordering ridges resulted in lines of consequent drainage from the ridges toward a central area of lower-lying ground, which, in the logic of circumstances, would be occupied by a shallow lake or series of lakes. Inasmuch as the drainage on the eastern side of the lakes came from the country lying on the east, we are able to affirm that at least the heavier sediments in the sandstone series on this side of the lakes had their origin in the eastern hills and to point to this section as the original home of the limestone pebbles in the conglomerate beds.

Over such a region a flow of lava poured forth, which accumulated in the low-lying areas occupied by the lakes, and spread out over the sloping ground along the border lines.

When we came to examine the lava itself we saw that it carried in its own mass plain evidences of the structural changes which were produced by the presence of the lakes and of the water-bearing strata beneath. Whereas beyond the borders of the lakes the lava was of a close, firm texture and showed a condition of quiet and tranquillity during the process of cooling and hardening, over the area of lake bottom there was evidence of violent agitation having affected it during the initial flows, and rapid cooling and the production of much glassy material during succeeding flows, followed still later by the crystallizing effects wrought by heated waters and the production of secondary minerals.

By an examination of the territory and a study of the structure of the trap sheet we are able to define approximately the shape of the area covered by the lake or lakes.

I have outlined on the map a tentative boundary. The lake itself seems a sufficiently distinctive feature of the ancient topography to receive a specific name, and I have called it Lake Paterson, from the locality where some of the most typical exposures are to be found.[1]

[1] In the *Transactions of the Geological Society of America* for 1897 (Vol. VIII, pp. 59 ff.) Professor B. K. Emerson gives a detailed description of the occurrence of sandstone inclusions in the Connecticut valley traps, which have many points of similarity to those of the New Jersey area. The theory by which he accounts for their presence, however, is, in some features, radically different from that offered here, chiefly in that it is based upon a fundamental conception that the lava was a submarine flow, covering the muddy bottom of a bay. While this may account for the features which he describes in the New England area, I think that the explanation proposed in the preceding pages will better account for the features of the trap sheet and for the relations of trap and sandstones in the New Jersey area.

THE SUCCESSION OF FAUNAS IN THE PORTAGE AND CHEMUNG FORMATIONS OF MARYLAND[1]

CHARLES K. SWARTZ
Johns Hopkins University

In April, 1904, the author visited Great Cacapon, Western Maryland, in company with Messrs. Charles Butts, G. W. Stose, and George C. Martin. At that time certain fossils were observed which, it was believed, might indicate the presence of the Ithaca fauna in Maryland. Subsequent and fuller investigations have been made which have confirmed this view.[2] As the extension of the Ithaca fauna into this area had not been previously noted, it is believed that a brief presentation of the results obtained may be of interest. A résumé of the history of the earlier investigations of the Upper Devonian formations of Maryland will be helpful in understanding the facts to be presented.

HISTORICAL REVIEW

In 1892 Mr. H. N. Darton proposed the name Jennings formation for the Upper Devonian rocks which lie below the Hampshire, and above the Romney in the Staunton, Virginia, quadrangle.[3] The name was subsequently adopted by the Maryland Geological Survey for similar strata in Maryland.

A detailed study of the Upper Devonian formations of western Maryland was made by Professor Charles S. Prosser, assisted by R. B. Rowe, C. C. O'Harra, and others in the years 1898, 1899, and 1900. The fossils collected were described by Dr. J. M. Clarke. A brief statement of the results obtained was published by Professor Prosser in the *Journal of Geology* in 1901.[4]

It was shown that the Jennings formation in Maryland embraces three members which are, in general, equivalent to the Genesee, Portage, and Chemung of New York.

[1] Published by permission of the Maryland Geological Survey.

[2] A brief statement of this fact was published in *Maryland Geol. Survey*, Vol. V, 1905, and in the Johns Hopkins University Circular, New Series, No. 7, p. 50, 1907.

[3] *American Geology*, Vol. X, 1892, p. 17.

[4] *Journal of Geology*, Vol. IX, pp. 419, 420, 1901.

The fossils described from the Portage were those characteristic of the Naples fauna of New York.[1] A thickness of approximately 2,000 feet was assigned to it in the central part of the area studied.[2]

All strata from which brachiopods were described were assigned to the Chemung. This fauna was known to contain two elements, one characteristic of the Ithaca fauna and another of recognized Chemung facies, while the two elements were supposed to be commingled in the Chemung of Maryland.

The Jennings, though comprising diverse elements, was mapped as a unit because it was deemed impracticable to attempt a cartographic separation of its members at that time.

It appears from the work here discussed that a considerable number of the species previously referred to the Chemung of Maryland occur in reality in the Ithaca facies of the Portage formation. The number of species thus far observed in it is not large, but they are represented by a profusion of individuals.

The various sections will be discribed, those in Washington County being first considered, then those in Allegany County, adjoining it on the west; their faunules will be analyzed, and the correlation of the faunules with those of New York will be finally discussed.

The present article is a preliminary discussion of the results obtained. The author wishes to acknowledge his indebtedness to Mr. D. W. Ohern, Fellow in Johns Hopkins University, for much assistance, particularly in mapping the divisions in Allegany County, and in the measurement and detailed study of a number of the sections.

SECTIONS IN WASHINGTON COUNTY

The Genesee is absent in Washington County.

Great Cacapon.—This section is situated north of the Potomac River opposite Great Cacapon, West Virginia, 8½ miles southwest of Hancock, Md. The strata are well exposed in the cut of the Western Maryland Railroad, standing nearly vertical. They comprise the Portage and part of the Chemung. The base of the Jennings is well marked, on the east, by a massive sandstone which forms the top of the Romney, and which contains Hamilton fossils.

[1] *Journal of Geology*, Vol. IX, p. 420.

[2] *Maryland Geological Survey*, Vol. VI, Part I, p. 136, 1906.

The lower 500 feet of the Jennings contains only species of the Naples fauna. These are especially abundant at its base where occur

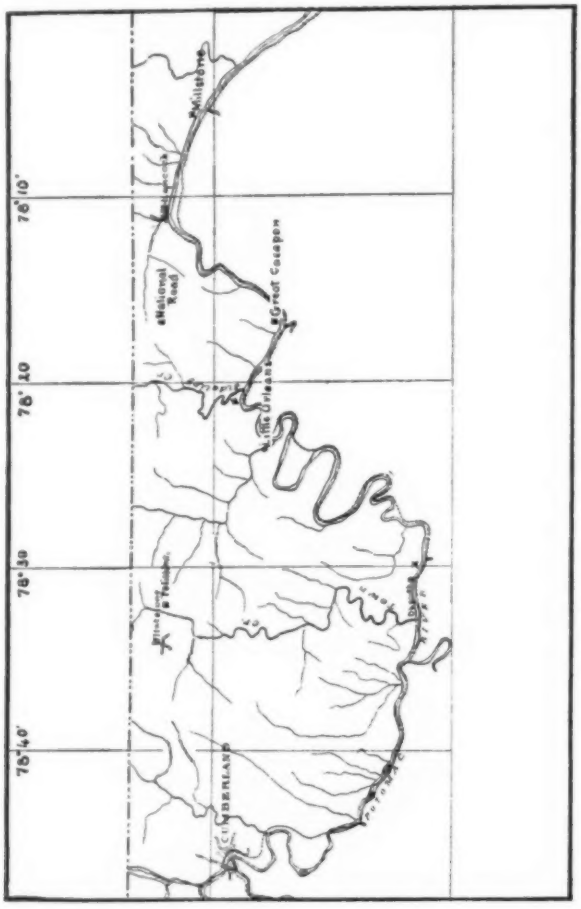


FIG. 1.—Map showing sections in Western Maryland.

various *Goniatites* together with species of the genera *Buchiola, Pterochaenia,* etc. A brachiopod fauna appears above this. At 520 feet above the base of the Jennings *Atrypa reticularis* (L.) occurs, apparently marking the advent of the new fauna. At 735 feet altitude

Schizophoria striatula (Schloth) was found, a species abundant in the Ithaca of New York, and at 785 feet *Spirifer pennatus* var. *posterus* Hall and Clarke, was observed.

At an altitude of 1,000 feet a profusion of individuals was found belonging to the following species:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall, abundant
Leiorhynchus globuliforme (Vanuxem), common
Pugnax pugnus (Martin), common
Cyrtina hamiltonensis Hall, common
Ectenodesma birostratum Hall, rare

Spirifer pennatus var. *posterus* has very long wings, while casts of the ventral valves are without median septum. Individuals of this species are very abundant and well characterized. The forms referred to *Productella speciosa* possess small umbos, and have rather thickly set spines, with small bases.

At 1,400 feet a conglomerate occurs which contains *Camarotoechia congregata*. This seems to be identical with a simularly situated conglomerate farther north, which contains *Camarotoechia congregata* and which will be shown to be referable to the horizon-bearing *Spirifer mesacostalis* at other localities. At 1,750 feet above the base of the Jennings *Spirifer mesastrialis* appears.

The faunules occurring between 520 and 1,000 feet altitude consist of species all of which occur in the Ithaca fauna of New York or Pennsylvania. *Spirifer pennatus* var. *posterus*, *Productella speciosa*, *Pugnax pugnus* and *Schizophoria striatula* are characteristic species of the Ithaca fauna of New York, while J. M. Clarke cites *Leiorhynchus globuliforme* as occurring frequently in the same fauna. *Cyrtina hamiltonensis* and *Ectenodesma birostratum* are cited by Kindle and Williams from the Ithaca fauna at Catawissa, Pa. The entire association therefore consists of species occurring elsewhere in the Ithaca fauna and contains no diagnostic Chemung forms. Its position is above the Naples fauna and below the *Spirifer disjunctus* fauna of this section. Thus both in composition and position it appears to be referable to the Ithaca fauna.

In order to ascertain whether Chemung forms may not be mingled with these species at other places, a careful examination was made of similar horizons in a number of localities.

National Road west of Tonoloway Ridge.—The section is exposed along the National Road east of the schoolhouse. The strata dip at high angles and are more or less complicated by minor folds. It is upon the strike northeast of the Great Cacapon section.

The top of the Romney is marked by a massive sandstone which is exposed 250 feet east of the schoolhouse. *Goniatites*, *Buchiola*, etc., occur at the base of the Jennings as in the preceding section, representing the Naples fauna. At 830 feet above the base of the Jennings occur *Spirifer pennatus* var. *posterus* Hall and Clarke, *Schizophoria striatula* (Schloth) and *Productella speciosa* Hall. At 950 feet the following species were observed:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall, abundant
Pugnax pugnus (Martin), common
Leiorhynchus globuliforme (Vanuxem), common
Cyrtina hamiltonensis Hall, common

At 1,020 feet *Spirifer pennatus* var. *posterus* aand *Productella speciosa* were observed. A yellow iron-stained conglomerate abounding in *Camarotoechia congregata* (Conrad) occurs at about 1,350 to 1,400 feet above the base of the Jennings. Red bands are seen beneath it. This conglomerate seems to be identical with a similarly situated conglomerate east of Hancock, which there contains *Spirifer mesacostalis*. *Spirifer disjunctus* and its associated forms are found at still higher horizons.

The faunules are thus seen to be similar to those of the Great Cacapon section, which they closely resemble both in composition and altitude. All the species found between 820 and 1,020 feet altitude are found in the Ithaca fauna in New York.

National Road east of Hancock, Md.—The section described is exposed on the National Road beginning just east of the village and extending eastward to Tonoloway Creek. The top of the Romney is marked by a heavy sandstone exposed along the road east of the stream, east of the Catholic church. The Naples fauna was found in the lower part of the Jennings, while above it the following faunules were collected.

750 feet above the base, *Schizophoria striatula* (Schloth)

1000–1100 feet above the base, *Spirifer pennatus* var. *posterus* Hall and Clarke, abundant.

Productella speciosa Hall, abundant
Leiorhynchus globuliforme (Vanuxem), common
Cyrtina hamiltonensis Hall, common
Lingula spatulata Vanuxem?
Spirifer mesastrialis Hall, rare

The above faunule suggests that found at 1,000 feet altitude at Great Cacapon. About 1,500 feet above the base of the Jennings occurs an iron-stained conglomeratic sandstone 1 foot thick, loaded with *Camarotoechia congregata* (Conrad), and bearing also *Camarotoechia eximia* Hall? and *Spirifer mesacostalis* Hall. The latter shows a strongly developed median septum in the ventral valve. Red bands appear just below this stratum, which seems to be identical with the similarly situated conglomerate already mentioned in the preceding section. *Tropidoleptus carinatus* Conrad was obtained in apparently the same horizon south of the Potomac River. About 2,100 feet above the base of the Jennings (at the turn of the road west of Tonoloway Creek) occur:

Spirifer mesastrialis Hall
Chontes scitulus Hall
Ambocoelia umbonata (Conrad)
Orthoceras sp.

Fifty feet above the latter *Spirifer disjunctus* was found.[1]

Harrisonville Road.—This section is exposed on the Harrisonville Road two miles north of Hancock and one mile east of Dogtown, Pa. The lower part of the Jennings contains the Naples fauna. Seven hundred and twenty-five feet above the base of the Jennings the following species were obtained:

Atrypa reticularis (L).
Pugnax pugnus (Martin).
Schizophoria striatula (Schloth).
Camarotoechia sp.
Aulopora (?) sp.

It will be observed that the lower brachiopod fauna appears at about the same altitude in the Great Cacapon section.

Millstone.—This section is exposed on the Western Maryland Railroad one-half mile east of Millstone, and five miles east of Han-

[1] This section is complicated by minor folds. The measurements are taken from the section at Berkley Spring which is on the strike of the section discussed and is free from folds.

cock. West of a ravine, one-half mile east of Millstone, occurs a massive conglomeratic sandstone 25 feet thick, bearing the following species:

Spirifer mesastrialis Hall, common
Orthothetes chemungensis (Conrad)
Schizodus gregarius Hall (?), common

The two latter species are poorly preserved.

Two hundred and fifty feet above the preceding occurs a very thick and massive conglomerate, while 370 feet higher *Spirifer disjunctus* was observed. A short distance above the latter *Spirifer mesastrialis* is abundant.

One hundred and eighty feet below the first-named sandstone *Camarotoechia congregata* and *Spirifer mesacostalis* occur as at Hancock in an iron-stained stratum.

Four hundred and sixty feet beneath the *Camarotoechia congregata* zone the following species were observed:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall, common
Leiorhynchus globuliforme (Vanuxem)
Cyrtina hamiltonensis Hall

This faunule resembles the *Spirifer pennatus* var. *posterus* faunule of the preceding sections, both in position and composition.

SECTIONS IN ALLEGANY COUNTY

The sections will be examined in their order from east to west. The Genesee is present at the base of the Jennings in this county.

Sideling Creek.—The section is exposed on the west bank of Sideling Creek two miles above its confluence with the Potomac. The stratum there exposed is the lowest observed horizon containing *Spirifer mesacostalis, Camarotoechia congregata,* etc. This horizon is more or less conglomeratic in character at most localities, and is believed to represent the western extension of the conglomeratic sandstone bearing *Camarotoechia congregata* and *Spirifer mesacostalis* in the section in Washington County. It is highly fossiliferous, the following species being observed in it:

Atrypa reticularis (L.)
Camarotoechia congregata (Conrad)
Cyrtina hamiltonensis Hall

Productella lachrymosa Conrad
Spirifer mesacostalis Hall
S. marcyi Hall var.
Tropidoleptus carinatus (Conrad)
Goniophora sp.
Cypricardella bellistriata (Conrad)
C. gregaria (Hall)
Nuculites oblongatus Conrad
Leptodesma sp.
Bellerophon maera Conrad
Bellerophon sp.
Bellerophon n. sp.
Cyclonema concinnum Hall
C. hamiltoniae
Coleolus tenuicinctus Hall
Euomphalus laxus Hall
Murchisonia sp.
Pleurotomaria itys Hall
Pleurotomaria n. sp. resembles *P. rotalia* Hall
Phacops rana Green
Bryozoa

Little Orleans.—This section is exposed in the cut of the Western Maryland Railroad. A conglomeratic sandstone occurs just west of the tunnel, bearing the following species:

Spirifer mesacostalis Hall, abundant
Camarotoechia congregata (Conrad), abundant
Nuculites oblongatus Conrad
Goniophora sp.
Bellerophon maera Conrad, abundant
Bellerophon n. sp., approaches *B. acutilira* Hall
Murchisonia n. sp., abundant

The following species were found somewhat below the above horizon, by the wagon road above the railroad:

Cyrtina hamiltonensis Hall
Pugnax pugnus (Martin)
Spirifer pennatus var. *posterus* Hall and Clarke
Leiorhynchus globuliforme Vanuxem
Tropidoleptus carinatus (Conrad)
Productella speciosa Hall
Schizophoria striatula (Schloth)
Stropheodonta demissa Conrad
Ectenodesma birostratum Hall

Nuculites oblongatus Conrad
Palaeoneilo brevis Conrad (?)
Bellerophon maera Conrad
Bellerophon n. sp., approaches *B. acutilira* Hall

It will be observed that this faunule, both in position and composition, is quite similar to the *Spirifer pennatus* var. *posterus* faunule which lies below the conglomerate in the Great Cacapon section.

Fifteen-Mile Creek.—This section is seen on Fifteen-Mile Creek one mile above Little Orleans. A conglomerate is there exposed bearing abundant *Camarotoechia congregata* and *Spirifer mesacostalis.* Three hundred feet below the latter the following species were obtained:

Spirifer pennatus var. *posterus* Hall and Clarke, abundant
Productella speciosa Hall
Schizophoria striatula (Schloth), common
Cyrtina hamiltonensis Hall, common

The relations are here as in the preceeding sections.

Polish Mountain near Gilpin.—This section is exposed along the National Road on the western flank of Polish Mountain. Black shales bearing characteristic Genesee fossils occur at the base of the Jennings southwest of the bridge. The Naples fauna is found in the lower part of the Jennings east of the bridge. Twelve hundred feet above the base of the Jennings at the second turn of the road east of the bridge, the following species were observed:

Spirifer mesacostalis Hall
Spirifer marcyi Hall var.
Tropidoleptus carinatus (Conrad)
Camarotoechia sp.

Fourteen hundred feet above the base of this section *Spirifer mesacostalis* Hall was observed and at 2,000 feet *Spirifer disjunctus* was found.

Section east of Okonoko.—Twelve miles south of the preceding section the Jennings is admirably exposed in the vicinity of Okonoko, in the cuts of the Western Maryland Railroad, north of the Potomac River. About 6,000 feet east of the canal lock, the Hampshire-Jennings contact is observed. At 1,350 feet below the top of the Jennings occurs a massive conglomerate, 20 feet thick. At 3,200 feet below the contact, *Spirifer mesacostalis* was found associated with

Camarotoechia sp. On the eastern limb of an anticline whose axis is 250 lower, the following species were observed:

Spirifer pennatus var. *posterus* Hall and Clarke
Leiorhynchus globuliforme (Vanuxem)
Cyrtina hamiltonensis Hall
Schizophoria striatula (Schloth).

This suggests the S*pirifer pennatus* var. *posterus* faunule of the preceding sections.

Cumberland.—An excellent section is exposed on the Williams Road about 3½ miles east of Cumberland. The Genesee occurs at the base of the Jennings, above which the Naples fauna was found. The lowest horizon of brachiopods observed contained the following species:

Spirifer marcyi Hall var.
Tropidoleptus carinatus (Conrad)
Chonetes scitulus Hall
Productella speciosa Hall
Camarotoechia sappho Hall (?)
Leptodesma sp.
Orthoceras sp.

Spirifer mesacostalis was found, apparently at the same horizon, a short distance southwest of this locality. The *Spirifer pennatus* var. *posterus* fauna has not been observed in this section.

Allegany Grove.—The section is exposed in the cuts of the C. P. and G. C. C. R. R., extending from the Winchester road westwards. The lower Jennings is abnormally thin in this section, as is also the Romney. This is probably due to compression in folding. The Naples fauna was found near the base of the section. The following species were observed at the altitudes named, above the base of the Jennings:

675 feet altitude, *Camarotoechia congregata* (Conrad)
850 " " *Productella speciosa* Hall (?)
850 " " *Leiorhynchus mesacostale* Hall (?)
850 " " *Cyrtina hamiltonensis* Hall
850 " " *Pterinea chemungensis* Conrad
1,100 " " *Spirifer mesacostalis* Hall, abundant
1,400 " " *Spirifer mesacostalis* Hall, abundant
1,600 " " *Orthothetes chemungensis* (Conrad)
1,800 " " *Stropheodonta* (*Douvillina*) *cayuta* Hall
1,800 " " *Orthothetes chemungensis* (Conrad)

The species occurring at 850 feet altitude are rare and poorly preserved. In position and composition they seem to be referable to the *Spirifer pennatus* var. *posterus* fauna which would appear to be very slightly developed here. *Spirifer disjunctus* occurs at 1,300 feet above the base of the Jennings at Ellerslie, six miles northeast on the strike of the preceding section.

ANALYSIS OF FAUNAS

An examination of the preceding lists shows that certain faunas may be discriminated in the Upper Devonian of Maryland, which are

TABLE I

SPECIES OBSERVED IN THE *Spirifer pennatus* VAR. *posterus* FAUNA

	Occurrence in		
	Hamilton	Portage	
		New York	P'nsylvania
Atrypa reticularis (L.), r	*	*	*
Camarotoechia congregata (Conrad), r	*	*	
Cyrtina hamiltonensis Hall, c	*	*	*
Leiorhynchus globuliforme (Vanuxem), c		*	?
Leiorhynchus mesacostale Hall, rr		*	*
Lingula spatulata Vanuxem, r		*	
Productella speciosa Hall, a		*	*
Pugnax pugnus (Martin), c		*	*
Schizophoria striatula (Schloth), c	*	*	*
Spirifer mesastrialis Hall, rr		*	*
Spirifer pennatus var. posterus Hall & Clarke, a		*	*
Stropheodonta demissa Conrad, r	*	*	*
Tropedoleptus carinatus Conrad, r	*	*	*
Nuculus oblongatus Conrad, r	*	*	
Palaeoneilo brevis Hall (?), r		*	*
Ectenodesma birostratum Hall, c			*
Pterinea chemungensis Conrad, rr			*
Bellerophon sp., r			
Bellerophon n. sp., r			
Bellerophon maera Conrad		*	*
Bellerophon n. sp. approaches B. acutilira Hall			

well characterized both by their composition and position. They may be designated as follows:

Spirifer disjunctus fauna
Spirifer mesacostalis fauna
Spirifer pennatus var. *posterus* fauna
Naples fauna
Genesee fauna

These faunas are to be traced throughout most of the area discussed. Their relations are indicated upon the accompanying chart. Their constancy of composition, shown by their predominating species, and their occurrence at the same relative position in the various sections, seem to indicate that they are recognizable units, and that they preserve their integrity throughout the area discussed. If we assume that the species occurring in the same relative position in the various sections belong to one fauna, the lists in Tables I and II may be taken as

TABLE II

SPECIES OBSERVED IN THE *Spirifer mesacostalis* FAUNA

	OCCURRENCE IN		
	Hamilton	Portage	
		New York	P'nsylvania
Atrypa reticularis (L.), r	*	*	*
Camarotoechia congregata (Conrad), aa	*	*	
Camarotoechia eximia Hall, r	*	*	*
Camarotoechia sappho Hall (?), r	*		*
Cyrtina hamiltonensis Hall, c	*	*	*
Chonetus scitulus Hall	*	*	*
Productella lachrymosa (Conrad), a		*	
Lingula sp			
Spirifer mesacostalis Hall, aa		*	
Spirifer marcyi Hall var	*	*	
Tropidoleptus carinatus (Conrad), aa	*	*	*
Goniophora glaucus Hall	*		
Goniophora sp			
Goniophora n. sp			
Cypricardella bellistriata (Conrad)	*		*
Cypricardella gregaria (Hall)	*		*
Nuculites oblongatus Conrad	*	*	
Leptodesma sp			
Bellerophon maera Conrad		*	*
Bellerophon sp			
Bellerophon n. sp			
Bellerophon n. sp. approaches B. acutilira Hall	*		
Cyclonema concinnum Hall	*		
Cyclonema hamiltoniae Hall	*		
Coleolus tenuicinctus Hall	*		
Euomphalus laxus Hall	*	*	
Murchisonia sp	*	*	
Murchisonia n. sp			
Pleorotomaria itys Hall	*	*	
Pleurotomaria n. sp. resembles P. rotalia Hall	*		
Platyceras sp			
Platyceras n. sp			
Orthoceras sp			
Trochoceras n. sp			
Phacops rana Green	*	*	
Bryozoa, 2 species			

indicating all the species thus far observed in each fauna. (Only those occurring in the three lower brachiopod faunas will be cited here.)[1]

CORRELATION OF THE FAUNAS

We may now examine the problem of the correlation of the Upper Devonian faunas of Maryland with those of New York and Pennsylvania by the use of the data given above.

Genesee Fauna.—The Genesee of Maryland, as has been shown by earlier students of the problem, bears a fauna very similar to that of the Genesee of New York which it also resembles in thinning out and disappearing toward the east.

Naples fauna.—Above the Genesee, in the western sections, or immediately overlying the Hamilton, in the eastern sections, are smooth fissile shales and interbedded sandstones carrying *Goniatites, Buchiola, Pterochaenia*, etc., as in the Naples fauna of New York. These strata are about 700 feet thick in the Allegany Grove Section. They increase considerably in thickness in the vicinity of Cumberland, and thin to about 500 feet in the eastern sections. The correlation of this division has been previously discussed by Professor Prosser[2] who assigned to it a thickness of about 2,000 feet in the central part of the area.[3]

Spirifer pennatus var. *posterus fauna.*—This fauna occurs immediately above the Naples fauna. It is of wide extent and is especially developed in the eastern sections. It is characterized by the abundance of *Spirifer pennatus* var. *posterus, Productella speciosa, Pugnax pugnus, Cyrtina hamiltonensis, Schizophoria striatula*, and *Leiorhynchus globuliforme* at most of its localities. The complete list of species observed in it is given on a preceding page. Of these, five, *Spirifer pennatus* var. *posterus, Productella speciosa, Tropidoleptus carinatus, Cyrtina hamiltonensis, Spirifer mesastrialis*, and *Leiorhynchus mesacostale* are placed by Williams[4] among the dominant species of the Ithaca fauna, which he has named the *Productella speciosa* fauna, while *Pugnax pugnus* and *Schizophoria striatula* are also prominent members of that fauna. *Leiorhynchus globuliforme* is also quoted by

[1] The new species here cited will be described later in the *Report on the Devonian of Maryland*, to be issued by the Maryland Geological Survey.

[2] *Journal of Geology*, Vol. IX, pp. 419, 420, 1901.

[3] *Maryland Geology Survey*, Vol. VI, Part I. p. 136, 1906.

[4] *Bulletin of the U. S. Geological Survey*, No. 210, p. 74, 1903.

Clarke[1] as frequently present in it in New York. It contains one species, *Pterinea chemungensis*, which is stated by Williams to be characteristic of the Chemung of New York.[2] This species is, however, cited from the Ithaca of New York by Clarke[3] and is quoted by Williams and Kindle[4] in what they regard as the Ithaca fauna in the Catawissa, Pa., fauna. The occurrence of this species therefore does not seem sufficient to determine the Chemung age of the fauna. All the species contained in the list, save one, are found in the Ithaca fauna of New York,[5] and that exception, *Ectenodesma birostratum*, is found in the Ithaca fauna in the section at Catawissa, Pa.[6] These facts would seem to indicate the Ithaca age of this fauna.

It is interesting to note that *Ectenodesma birostratum* and *Pterinea chemungensis* are restricted to the upper zone of the Ithaca fauna of the Catawissa section, and are also restricted to the upper zone of the fauna in Maryland. Indeed, there are numerous resemblances between the upper horizons of the two sections.

There is also a resemblance between this fauna and the Leiorhynchus globuliforme fauna found above the Onconta sandstone of New York, as shown by the following list of species of brachiopods occurring at Cowles Hill, Greene, New York.[7]

Atrypa reticularis
Schizophoria impressa (=*S. Striatula*)
Leiorhynchus globuliforme
Spirifer mucronatus (=*pennatus*) var.
Productella speciosa
Strophеodonta demissa
Spirifer laevis
Cyrtina recta
Leptostrophia mucronata

The resemblance is very close. It will be noted that *Spirifer laevis* is quoted by Kindle and Williams from the upper zone of the Ithaca

[1] *Ithaca Fauna of Central New York*, Bulletin 82, N. Y. State Mus., p. 64, 1905.

[2] *Journal of Geology*, Vol. XV, p. 98, 1907.

[3] *Bulletin 82*, N. Y. State Museum, p. 62, 1905.

[4] *Bulletin of the U. S. Geological Survey*, No. 244, p. 77, 1905.

[5] *Bulletin 82*, N. Y. State Mus., pp. 61–65, 1905.

[6] Kindle and Williams, *Bulletin of the U. S. Geological Survey*, No. 244, p. 77, 1905.

[7] *49th Ann. Rept.* for 1895, N. Y. State Museum, Vol. II, pp. 36–38, 1898.

fauna at Catawissa, Pa. Clarke[1] and Prosser[2] refer the Cowles Hill fauna to the Chemung, Williams to the Ithaca.

Spirifer mesacostalis fauna.—This fauna occurs above the preceding and is present throughout the entire area. Its dominant forms are *Tropidoleptus carinatus, Spirifer mesacostalis, Spirifer marcyi* and many gastropods. The list of species observed is given on a preceding page. Many of these have marked Hamilton affinities. This is especially true of the dominant brachiopods which include:

Tropidoleptus carinatus (Conrad)
Camarotoechia congregata (Conrad)
Spirifer mesacostalis Hall (cf. *S. consobrinus* of the Hamilton)
Spirifer marcyi Hall var.
Cyrtina hamiltonensis Hall

Goniophora glaucus Hall, *Coleotus tenuicinctus* Hall, and *Phacops rana* are also suggestive of Hamilton affinities. One species, *Productella lachrymosa* is quoted by Williams[3] as diagnostic of the Chemung in the Watkins, New York, quadrangle. Clarke, however, quotes it as of frequent occurrence in the Ithaca further east.[4] All of the forms specifically determined, save *Cyclonema concinnum*, are found in the Ithaca fauna.[5] These facts seem sufficient to refer this fauna to the Portage formation. In certain respects it resembles the Enfield fauna of Williams which, according to him, lies in the Nunda above the Ithaca and below the Chemung in the Watkins quadrangle. The following species of the above list are quoted by him as characteristic of that horizon: *Tropidoleptus carinatus, Spirifer marcyi, Delthyrus mesacostalis*, and numerous gastropods.[6] It will be noted that this fauna occupies a similar position in Maryland.

Spirifer disjunctus fauna.—The lowest observed occurrence of *Spirifer disjunctus* is in general 400–700 feet above the base of the *Spirifer mesacostalis* fauna. With it are associated *Douvillina cayuta* and *Camarotoechia contracta*, which have not been observed in the preceding faunas. *Spirifer mesastrialis* is also abundant in the fauna while it has been observed but rarely at lower horizons in Maryland.

[1] *49th Ann. Rept.*, for 1895, N. Y. State Museum, Vol. II, p. 39, 1898.
[2] *Ibid.*, p. 165.
[3] *Journal of Geology*, Vol. XV, p. 98, 1907.
[4] *Bulletin 82*, N. Y. State Museum, p. 64, 1905.
[5] *Ibid.*, pp. 61–65.
[6] *Journal of Geology*, Vol. XV, p. 109, 1907.

PORTAGE-CHEMUNG BOUNDARY

It is very difficult to determine this horizon when the brachiopod facies of the Portage immediately underlies the Chemung. Of the New York section Clarke remarks "It is extraordinarily difficult to fix on a division plane between the Ithaca and the overlying Chemung faunas."[1] If this be true in New York, it must be still more true when an attempt is made to correlate that section with those of other states, and the results attained must be open to revision as fuller investigations give increased data. Nevertheless, it seems reasonably probable from the preceding studies, that the horizon in question is to be placed between the strata bearing the *Spirifer disjunctus* and *Spirifer mesacostalis* faunas, giving the following succession:

Chemung, Spirifer disjunctus fauna
Portage { Spirifer mesacostalis fauna
Spirifer pennatus var. posterus fauna
Naples fauna }
Genesee, Black shales with Buchiola fauna

Lithologically the horizon is not well defined, the conditions varying at different localities. In general the Portage is characterized by smooth fissile shales and interbedded sandstones and the Chemung by a larger percentage of sandstones, while its shales are softer and break with a hackly fracture. The transition from Portage to Chemung is however not sharply defined by any lithological features.

GENERAL RELATIONS

Certain general facts seem to harmonize with those of New York.

1. The general succession of forms seems to be that of New York. At the base occurs the Genesee thinning eastward, followed by the Naples fauna of the Portage. Above the latter is found *Spirifer pennatus* var. *posterus*, succeeded by *Spirifer mesacostalis*, and finally by *Spirifer disjunctus*.

2. There is a greater development of the Naples fauna in the west and of the Ithaca fauna in the east.

3. The shore line was probably eastward as indicated by the fact that there is a marked development of conglomerates eastward, as at Millstone. These diminish toward the west where the lower Jennings is largely composed of argillaceous shales, as at Allegany Grove.

[1] *Memoir 6*, N. Y. State Museum, p. 213, 1904.

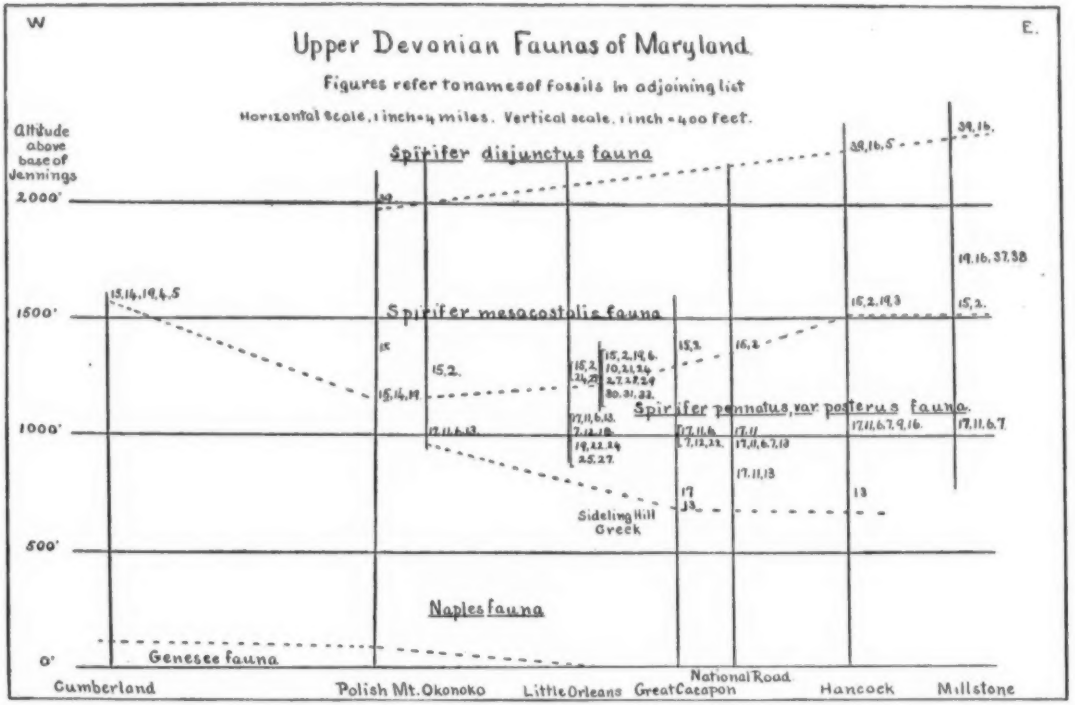

W
E.
Upper Devonian Faunas of Maryland
Figures refer to names of fossils in adjoining list
Horizontal scale, 1 inch = 4 miles. Vertical scale, 1 inch = 400 feet.
Altitude above base of Jennings
2000'
1500'
1000'
500'
0'
Spirifer disjunctus fauna
Spirifer mesacostalis fauna
Spirifer pennatus, var. posterus fauna.
Naples fauna
Genesee fauna
Sideling Hill Creek
Cumberland
Polish Mt.
Okonoko
Little Orleans
Great Cacapon
National Road
Hancock
Millstone

FIG. 2

TABLE III

UPPER DEVONIAN FAUNAS OF MARYLAND

The numbers on accompanying chart indicate the fossils of subjoined list. Only forms specifically identified from the brachiopod fauna of the middle and lower Jennings are recorded.

	HAMILTON	PORTAGE		PORTAGE OR HAMILTON
		New York	Pennsylvania	
1. Atrypa reticularis (L.)	*	*	*	*
2. Camarotoechia congregata (Conrad)	*	*		*
3. Camarotoechia eximia Hall	*	*	*	*
4. Camarotoechia sappho Hall (?)	*	*		*
5. Chonetes scitulus Hall	*	*	*	*
6. Cyrtina hamiltonensis Hall	*	*	*	*
7. Leiorhynchus globuliforme (Vanuxem)		*	?	*
8. Leiorhynchus mesacostale Hall		*	*	*
9. Lingula spatulata Vanuxem		*		*
10. Productella lachrymosa (Conrad)		*		*
11. Productella speciosa Hall		*	*	*
12. Pugnax pugnus (Martin)		*	*	*
13. Schizophoria striatata (Schloth)	*	*	*	*
14. Spirifer marcyi Hall var		*		*
15. Spirifer mesacostalis Hall		*		*
16. Spirifer mesastrialis Hall		*	*	*
17. Spirifer pennatus var. posterus Hall & Clarke		*	*	*
18. Stropheodonta demissa Conrad	*	*	*	*
19. Tropidoleptus carinatus (Conrad)	*	*	*	*
20. Cypricardella bellistriata (Conrad)	*		*	*
21. Cypricardella gregaria (Hall)	*	*		*
22. Ectenodesma birostratum Hall			*	*
23. Goniophora glaucus Hall	*			*
24. Nuculites oblongatus Conrad	*	*		*
25. Palaeoneilo brevis Hall?		*	*	*
26. Pterinea chemungensis Conrad	*	*		*
27. Bellerophon maera Conrad		*	*	*
28. Cyclonema concinnum Hall?				
29. Cyclonema hamiltoniae Hall	*			*
30. Euomphalus laxus Hall	*	*		*
31. Pleurotomaria itys Hall	*	*		*
32. Coleolus tenuicinctus Hall	*	*		*
33. Phacops rana Green	*	*		*
34. Ambocoelia umbonata (Conrad)				
35. Dalmanella tioga Hall				
36. Douvillina cayuta Hall & Clarke				
37. Orthothetes chemungensis (Conrad)				
38. Schizodus gregarius Hall				
39. Spirifer disjunctus Sowerby				

4. An interesting additional feature is that there is an earlier development of red beds in the eastern sections. Red strata appear below the top of the Portage in the east, but become marked only toward the

close of the Chemung in the western sections, a fact noted by earlier investigators of the Jennings.

5. The Chemung closes with the incoming of the nearly unfossiliferous red strata of the Hampshire, which are similar to those of the Catskill of New York.

The facts given indicate that the Ithaca fauna extends southward into Maryland, and that there was a general agreement in many of the conditions in New York and Maryland in Portage and Chemung time.

ANCIENT WATER-PLANES AND CRUSTAL DEFORMATION

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In a recent bulletin of the Wisconsin Geological Survey,[1] Goldthwait has presented the results of an interesting study of the strands of the ancient Great Lakes as they occur in eastern Wisconsin. The field-work is much more detailed and accurate than the average, and the success in reconstructing the complex series of shore-lines of Lake Algonquin, in the region studied, is largely the result of using a wye level, instead of a hand level, or aneroid barometer, in determining the heights of the ancient beaches and terraces above the present lake level as a datum plane.

By far the greater part of the report is devoted to the descriptions of the old shore-lines and a review of previous work. And the conclusions on p. 42 bear only on the history of the ancient Great Lakes. In chap. iv, however, the author takes up the question of the deformation of the Great Lakes region and presents a new hypothesis as to the character of the crustal movements which have deformed the ancient shore-lines.

The hypothesis in brief is: that tilting of the earth's crust took place on the north side of axes which moved northward at intervals, resulting in the originally horizontal Algonquin beach-lines being given a broken profile with progressively steeper slopes northward. The movement was such as to tilt the surface of any block without warping. The idea expressed, it will be seen, is more definite than that of the older hypothesis of "differential warping" and may be spoken of as "differential tilting."

In this article it is desired to analyze the data upon which these hypotheses rest in order to form some idea as to their probable error, and also to compare the two hypotheses in order to see which is the

[1] J. W. Goldthwait, "The Abandoned Shore-Lines of Eastern Wisconsin," *Wisconsin Geological and Natural History Survey*, Bull. No. XVII, Sci. Ser., No. 5, 1907.

more probable. The result will show that both hypotheses are equally probable, but as that of differential warping involves simpler assumptions, it is considered preferable in our present state of knowledge concerning the subject.

As ideas in regard to the character of crustal movements in the Great Lakes region are based upon the water-planes reconstructed from observations upon the beaches, terraces, and other shore-line features of the ancient Great Lakes, it seems advisable first to consider the several errors that may enter into the determination of the position of such water-planes. These errors have been recognized for many years, and statements respecting most of them may be found in various reports dealing with both the ancient and modern Great Lakes. They have not, however, been collected in any one article, so far as the reviewer knows. It seems appropriate, therefore, to bring them together and point out the limitations they impose upon the correlation of old shore-lines and the deductions that may be drawn from reconstructed water-planes in regard to the character of the deformation of the Great Lakes region, especially as work in this field is now being placed upon a more accurate and refined basis.

The errors that enter into the determination of the height of the ancient beaches, etc., above the present lake levels—the datum planes—need only brief consideration, since with proper care they may be practically eliminated. The principal ones are, perhaps, those connected with the measurements of heights, seasonal fluctuations of the lake level, and changes in level by winds and waves. The first one can only be reduced to a negligible quantity by the use of a wye level, the instrument adopted by Spencer, Lawson, Upham, and Goldthwait in their work. The second may be eliminated by applying to the altitude determinations a correction obtained from a continuous record of the fluctuation of the lake level, a correction that was applied by Goldthwait. The last two errors appear rather troublesome, though they may be largely eliminated by restricting work to calm days. To do this, however, might often prove inconvenient, and it may be assumed that an error of from 1 to 2 feet[1] may arise from these causes.

The more important errors are connected with the location of water-planes with respect to ancient beaches and terraces, with the

[1] Goldthwait, *op. cit.*, p. 100.

former larger fluctuations in water-levels, and with other points that will be taken up in categorical order.

1. The exact position of an old water-plane is very difficult to determine because of its variable relation to different beaches, terraces, and other shore forms. The common practice has been to take the top of a beach ridge as fixing the position of the old water-plane, "although it is of course recognized that the beach ridge probably stood anywhere from 3 to 6 feet above the actual water-plane."[1] If in the case of a true beach ridge the actual water-plane will average 3 feet below the top of the ridge, elevations should be corrected by this amount in order to bring them as near the true water-plane as possible. If observations were entirely upon beaches this correction would be a constant and might be omitted in considering the relative displacements suffered by the shore-lines. But as they are also made upon terraces, spits, and bars, which require different assumptions in regard to the height of the water-plane, the above correction should be applied, otherwise the observations are not comparable within the assumed limit of 3 feet. In the case of a cut terrace the foot of the bluff is taken as fixing the position of the water-plane, although the true water-plane may have been as much as 2 feet either above or below that point. Where a terrace is cut in unconsolidated material the actual water-plane would in most instances be above the foot of the bluff and a correction might be applied to allow for this. Where terraces are cut in rock its location would depend upon the character and dip of the strata. In this instance a close study of present conditions might furnish a correction that could be applied in certain cases at least.

2. The variability in the position of a beach ridge with respect to the water-plane may particularly be noted. While a "normal" beach may be 3 feet above the surface of the water, storm beaches as much as 6 feet above the lake level may be considered as common, and a few have been reported at still higher elevations. Unless such beaches are situated so that their true nature can be recognized by comparison with neighboring shore-line features, they may introduce serious errors. One will be noted in the next paragraph. Storm beaches are formed, of course, only on the exposed parts of the shore-

[1] Goldthwait, *op. cit.*, p. 100.

line and evidently vary in height on the shores of different lakes. The configuration of the shore and its relation to the direction of storms exercise a great influence on the height of such beaches, and many interesting observations have been made on this point.[1] Lawson states[2] that on the north shore of Lake Superior he measured crests of living beaches facing the open lake at all elevations between 9 and 14 feet above calm water, while in less exposed parts of the shore they did not usually exceed 6 feet in height. Goldthwait,[3] for the western shore of Lake Michigan, sets the upper limit at 6 feet, and in one instance possibly at 8 or 9 feet. A correction should be applied to Lawson's figures, at least, to allow for the drop in the lake level from the high-water stage of 1886 to the 1891 stage on which his observations were based. This correction may be taken at 2 feet, so that the figures read 7, 12, and 4 feet, respectively. The error introduced by the variable position of a beach may be placed at 4 feet, allowance being made for the 3-foot correction above noted.

3. Cyclic fluctuations in water-level of the ancient lakes, due to short climatic variations, no doubt occurred as they do in the present lakes. The Milwaukee (Wis.) record shows an average change of 1.5 feet in the level of Lake Michigan from summer to winter. Lane says: "The water-level of the lakes at those (former) times undoubtedly varied from year to year and from month to month as it does now, probably in even more marked degree, as the cold of winter would have even more effect in checking the flow of water from the ice sheet;"[4] while Upham states: "Fluctuations of the lake level (in Lake Agassiz), which doubtless rose in summer a few feet higher than in winter because of variations in the volume of water supplied, have given a variability within the limits generally 5 feet and perhaps sometimes 8 or 10 feet apart to the heights of the lake and of its shore deposits

[1] Chas. Whittlesey, "Fluctuations in the Level of the North American Lakes." *Smithsonian Contributions to Knowledge.* Vol. XII; A. J. Henry, "Wind Velocity and Fluctuations of Water Level on Lake Erie," *U. S. Weather Bureau*, Bull. J., 1902.

[2] A. C. Lawson, "Coastal Topography of the North Side of Lake Superior," *Geological and National History Survey of Minnesota*, Twentieth Annual Report, p. 231.

[3] Personal communication.

[4] A. C. Lane, "Geological Report on Huron County, Michigan," *Geological Survey of Michigan*, Vol. VII, Pt. II, p. 65.

in different stages."[1] Much more important, however, are the changes in level that occur over a period of years rather than months. The record of the fluctuations of lakes Michigan and Huron from the year 1800 to 1899[2] is most instructive upon this point. The maximum change of level shown is 6 feet, while the average fluctuation between successive high and low stages, for all changes over 1 foot, is about 2.5 feet. What then is the true water-level? The question has a very direct bearing on the problem of fixing the position of the water-planes of the glacial Great Lakes from observations upon their shore-lines, since one beach formed in one decade might well be several feet higher or lower than a second constructed at another point in a following decade. Lane has noted the effect of such fluctuations in speaking of a 14-foot beach ridge in Huron County, Michigan. He says: "The water-line probably lay a little lower, at 10 or 11 feet above the 582-foot datum (the present lake level), at a time perhaps within range of tradition. . . . . The high water-line of 1886 is well marked in a crest from 4 to 7 feet above the present lake level."[3] The idea naturally suggests itself that a reconstructed water-plane, when drawn on a large enough scale, instead of being represented as a single line, should be shown as a zone of such a width as would take account of these changes of level.

As an extreme case, it may be supposed that at a time of maximum high water a storm beach was built up 6 feet above the water-level, while at a time of low water a terrace was cut 2 feet below the lake level. There would be a difference of 14 feet (8 in beach and terrace +6 in water-level) between the two, yet they would belong to the same period and might have been formed within 25 years of each other. Such an explanation may account for the discrepancy (of 10 or 12 feet) between a cut terrace and bowlder beach on the north shore of Lake Superior which Taylor believed belonged to the same shore-line. He says: "Measurements of the same shore-line often vary 7 or 8 feet, sometimes more, from this cause"[4] (one measure-

[1] W. Upham, "The Glacial Lake Agassiz," *U. S. Geological Survey, Monograph 25*, p. 277, 1896.

[2] Lane, *op. cit.*, Plate V. [3] *Op. cit.*, p. 76.

[4] F. B. Taylor, "The Nipissing Beach on the North Superior Shore," *American Geologist*, Vol. XV (1895), p. 307.

ment on a beach, the other on a terrace). Such discrepancies as just noted may give rise to large errors (50 per cent. or more) in the calculated gradient of a shore-line when the distance between the two points of observation is short. These larger fluctuations in water-level would prove especially troublesome where strong cutting or filling was occurring. When the water-plane is gradually dropping a blurring of shore forms frequently results, although this is not always the case as Goldthwait's profile at Jacksonport shows.[1] On the other hand, if the water-level remained constant for several years a well-marked terrace might easily be cut or a strong beach built, while with a drop to a new level, at which the water might again stand for some time, a second terrace or beach might be formed. As the record shows, differences of 2 or 3 feet would be common between such terraces and beaches. It seems difficult to escape the conclusion that a source of error in the reconstruction of water-planes exists here that cannot be eliminated. It may range from 0 to 6 and possibly a larger number of feet.

4. The quotation from Taylor, above given, raises the question whether the level of a water-plane can be judged more closely from cut terraces or beaches. From the fact that beaches show such wide variations in position with respect to the water-plane, it would seem probable that terraces furnished the best guide. Upham has stated: "Cliffs eroded by the lake waves give more definitely the plane of the water surface"[2] than beaches. This applies, however, only where the forms are well preserved. When they are not well preserved, it seems likely that a beach would be a better guide than a terrace, since the original surface of a terrace is more liable to become obscured than that of a beach. This brings up the point that both beaches and terraces in time become more or less eroded and covered with vegetation, thus making it difficult to tell just what point should be chosen in measuring their elevations, and leading to uncertainty in correlation. Lawson has said, in speaking of a certain locality on the north shore of Lake Superior, that "a series of terraces can be seen scoring the hills to the north at a distance of probably a little more than a mile and a half at the farthest. An effort was made to locate these terraces by running a line of levels from the railway, but this

[1] *Op. cit.*, p. 76. [2] *Op. cit.*, p. 277.

met only with partial success. The terraces which appeared so sharp and unequivocal from the railway station lost their character when approached closely, and could be recognized as terraces only with considerable doubt."[1] What error may be introduced through the alteration of original forms is difficult, perhaps, to say. In the case of beaches it would be small as compared with that resulting from the variable height of a beach above the water-level. For terraces the error would generally be somewhat greater, since the base of a bluff is frequently obscured by talus, wash, etc. An error of 1 foot may be assumed as due to this cause.

It will be recognized, of course, that observations in the field, that is, our so-called geologic facts, vary greatly in value, and in any refined work should be weighted accordingly. Observations on the ancient shore-lines, however, serve two purposes. The first is to unravel the history of the glacial Great Lakes and as continuous tracing of shore-lines is a very important part of this work, observations should be as numerous as possible. The second is to determine the character of crustal movements in the Great Lakes region. This is a different problem and the value of results depends upon the probable error of observation. In refined work this error should be reduced to a minimum, for which reason it would seem advisable to use, if possible, only those observations that have small errors.

5. Progressive climatic changes over long periods of time may also have produced important variations in the water-levels of the lakes. That such climatic changes occurred may reasonably be inferred from the pronounced movements of the continental ice sheet during that period. This factor may well have been of considerable importance, but is at present undeterminable. It is simply presented as one of the unknown factors in the problem of the history of the ancient Great Lakes which might alter conclusions were its value known.

6. Secular changes in the water-level due to (1) show crustal movements, and (2) changes produced by erosion in the elevation of outlets are to be noted. Errors arising from these sources may eventually be eliminated—when the history of the ancient lakes has been worked out in fuller detail. Attention, however, may be called to one condi-

[1] *Op. cit.*, p. 263.

tion which must be taken into account, namely, the gradual lowering of the water-level from one stage to another. The condition is similar to that described under (3), but is of greater magnitude. It necessitates representing the water-planes as zones of such a width as will include these variations in water-level.

7. Variations in the elevations of the old shore-lines would result from deformation of the water-level induced by local attraction of the ice sheet. The error introduced is small, though it would have to be taken into account in any consideration of the old shore-lines as a whole. For small areas, presumably remote from the ice sheet, it may be neglected.

It will be seen from the foregoing that there are several noticeable errors connected with the location of a water-plane with respect to ancient shore-lines. A calculation, which takes account of only the more important errors, gives the probable error of observation as ± 1.5 feet, the limit of error 10 feet.

While these errors affect to some extent the correlation of a series of ancient beaches, terraces, and related shore forms, it is desired to point out here the influence they have upon conclusions, based on the present attitude of the reconstructed water-planes, as to the character of the crustal movements in the Great Lakes region. This may be illustrated by fitting curves of different kinds to Goldthwait's very complete set of observations as they are plotted on Plate XXXVII of his report.

We may consider first that portion of the profile extending from Rock Island to Jacksonport, a distance of 35 miles, since this is the stretch in which the several ancient water-planes have been individually distinguished. For the sake of simplicity a straight line may be drawn through each of the series of observations representing the four water-planes A, A', B, and C. The deviations of all points of observation in each series from its respective straight line may then be measured, and likewise from the broken lines as drawn by Goldthwait. The results are as follows:

Average deviation of all sure points from straight lines	= 1.4	feet.
" " " " " " broken "	= 1.1	"
Maximum deviation of any sure point from straight "	= 4.0	"
" " " " " " broken "	= 4.0	"

Both the average and the maximum deviation in each case are within the probable error of observation and the limit of error respectively, so that the difference of 0.30 foot in favor of the broken lines possesses no significance. It may be shown likewise that a curved line would fit the observed points with no greater error than noted above.

The certain conclusion is reached, then, that either a straight, a curved, or a broken line may be drawn through the points of observation with equal accuracy, and that, consequently, in this distance of 35 miles the present attitude of the old shore-lines may be the result either of a uniform tilting, a differential warping, or a differential tilting of the earth's crust.

It may be said, however, that a distance of 35 miles is too short for a test of this character. We may consider, then, the entire length of the profile from Rock Island to Two Rivers, a distance of about 100 miles. In so doing the conclusion that the Algonquin beaches encircle the southern half of Lake Michigan as the "Toleston" beach, instead of descending beneath the level of the lake somewhere north of Two Rivers, will be assumed as correct.

The first thing to be noted is that a straight line cannot be drawn through the points of observation without far exceeding the probable error of observation. The hypothesis of uniform tilting, therefore, drops out. It appears possible, however, to fit a curve. For the sake of simplicity a circular curve, with a radius of approximately 11.75 feet, may be drawn through the points of observation as plotted on Goldthwait's profile, and the deviations of the points measured. The results are as follows: Average deviation of all sure points = 1.2 feet; maximum deviation of any sure point = 3 feet. The deviations of all the observed points from the broken profile of Goldthwait were not measured for the entire length of the profile, since it was evident that they would be essentially the same as measured for the profile from Rock Island to Jacksonport, namely, 1.1 and 4.0 feet respectively.

The conclusion may be stated, then, that the Algonquin shore-line for the whole length of the profile, about 100 miles, furnishes no evidence in favor of the hypothesis of differential tilting over the older one of differential warping; both are equally probable so far as the observations go. The hypothesis of differential warping, however,

involves a simpler assumption respecting the distribution of stresses within the earth's crust, and for this reason should be considered preferable to the hypothesis of differential tilting.

If earth movements in the Great Lakes region had been great instead of small, and the errors in the water-plane determinations small instead of great, the character of the crustal deformations might well be ascertained; but on the contrary we find the probable error of observation so large—it is expressed in feet, rather than tens of feet or in inches—that it leads to the impression that but little refinement of the old idea of differential warping is possible on the basis of the ancient shore-lines alone.

NOTICE OF A NEW COELACANTH FISH FROM THE IOWA KINDERHOOK

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The family of Coelacanth ("hollow spined") ganoids, first proposed by Agassiz in 1844, and subsequently emended by Huxley in two important memoirs of the *Geological Survey of the United Kingdom* (Decades X and XII), is at present understood as comprising not more than six satisfactorily known genera, among which Coelacanthus itself, Macropoma, and Undina are of paramount importance. The first-named of these, which is typical of the family and likewise of the group Actinistia, enjoys the truly remarkable geological range from the Upper Devonian to the close of the Paleozoic, or, if the evidence of certain doubtful indications be accepted, possibly even higher; the remaining genera continue throughout the Mesozoic, and exhibit such constancy of structural characters as to render the family one of the most compact and well defined in the animal kingdom.

Attention has frequently been called to the extraordinary conservatism and persistency maintained by the group throughout an unusually long life-period. Its singular history impressed both of the distinguished naturalists to whom we owe our principal knowledge of the family, Huxley's views upon the matter being thus stated by him:

> Bearing in mind the range of the Coelacanths from the Carboniferous [since ascertained to extend from the Devonian] to the Chalk formations inclusive, the uniformity of organization of the group appears something wonderful. I have no evidence as to the structure of the base and side-walls of the skull in Coelacanthus, but the data collected together in the present Decade shows that, in every other particular save the ornamentation of the fin-rays and scales, the organization of the Coelacanths has remained stationary from their first recorded appearance to their exit. They are remarkable examples of what I have called elsewhere "persistent types," and like the Labyrinthodonts, assist in bridging over the gap between the Paleozoic and the Mesozoic faunae.[1]

[1] *Mem. Geol. Surv. United Kingdom*, Decade XII (1866); reprinted in the supplementary volume of the *Scientific Memoirs of T. H. Huxley* (1903), p. 65.

The earliest known representative of the family is a small form occurring in the lower part of the Upper Devonian near Gerolstein, in the Eifel District, first described by A. von Koenen[1] in 1895, and referred by him with some hesitation to Holoptychius, but afterward recognized by Smith Woodward[2] as an undoubted Coelacanth, and transferred by him to the typical genus. Prior to this discovery the opinion had been generally entertained that, owing to the sudden appearance of Coelacanth fishes in a complete state of development in the Calciferous sandstones of Scotland, it was necessary to postulate the existence of their ancestors during the Devonian, notwithstanding their apparent failure to be preserved in both Europe and North America. In fact, the oldest remains of Coelacanth fishes hitherto found in this country are in strata of Coal Measure Age, and the few species that are known are poorly or at best indifferently preserved. Under these circumstances it is interesting to record the discovery, made by Dr. Stuart Weller a few years ago, of an unusually perfect example of Coelacanthus from the very base of the Mississippian series near Burlington, Iowa. The exact horizon whence the specimen was obtained is the blue shale bed forming the basal member of the Kinderhook limestone, and designated as No. 1 in the local section whose fauna is analyzed by Dr. Weller in Vol. X of the *Iowa Geological Survey Reports* (p. 69 ff.). In recognition of the important results achieved by the author of *Kinderhook Faunal Studies*, and also as a testimonial of personal regard, we have pleasure in presenting the following description under a specific title dedicated in his honor. It should be stated that the holotype is preserved in the Walker Museum of the University of Chicago, and for the privilege of studying it in behalf of the Iowa Geological Survey the writer desires to express here his indebtedness to Dr. Weller.

Cœlacanthus welleri, SP. NOV.

Holotype, a somewhat imperfect fish, the total length of which to the base of the caudal fin is about 19^{cm}, or a little more than three times the length of the head with opercular apparatus. Trunk

[1] A. Von Koenen, "Ueber einige Fischreste des norddeutschen und böhmischen Devons," *Abhandl. k. Ges. Wiss. Göttingen, phys. Cl.* (1895), Vol. XL, p. 28.

[2] A. S. Woodward, "Note on a Devonian Coelacanth Fish." *Geol. Mag.* (1898), Dec. 4, Vol. V, p. 529.

FIG. 1.—*Coelacanthus welleri*, sp. nov. From the basal member of the Kinderhook limestone; Burlington, Iowa. Lateral aspect of holotype showing nearly complete trunk, but deficient as to portions of the head and most of the fin structures, × 1/1.

robust, its maximum depth twice as great as that of the caudal pedicle. Anal and paired fins situated as in the typical species (*C. granulatus* Ag.), the greater part of the caudal and both dorsals not preserved. Operculum and cheek-plates ornamented with numerous fine antero-posteriorly directed spiniform ridges, their position being indicated in the worn condition by faint tubercles. Scales ornamented with numerous fine raised lines of ganoine, more or less continuous and rectilinear in arrangement, but when worn assuming the appearance of elongated tubercles. Lateral line scales with prominent raised tubules directed parallel with the body axis.

The characters serving chiefly to distinguish the present form from other species may be enumerated as follows: (1) The delicate spiniform ornamentation of the operculum and cheek-plates, together with the form and disposition of the latter; (2) the peculiar form of the mandibular ramus; (3) details of superficial scale ornament; and (4) prominence of the lateral line canal. Owing to the defective preservation of most of the fin structures, it is impossible to say in what respects, if any, these differ from the prevailing type. The cranial structure, however, offers a number of interesting points of comparison with other forms, as will be immediately pointed out. Be it noted in passing that the totality of characters by no means indicates a primitive forerunner of the family, but on the contrary bespeaks a typical Coelacanth as completely developed as any subsequent form with which we are acquainted. In this respect the Kinderhook species resembles the only well known British Coelacanth of an age anterior to the Coal Measures, namely *C. huxleyi*, from the Calciferous sandstones of southern Scotland.

With reference to the skull it is to be noted that the cranial roofing-bones are missing in the type specimen, and that a portion of the head in advance of the orbits has been fractured in such manner as to strip off the maxillary and other facial elements, at the same time exposing the anterior spatulate portion of the parasphenoid, together with the steeply inclined triangular palatine plates that abut against it on either side. The inferior border of the palatines, parasphenoid and vomer appears to have suffered somewhat from chemical corrosion, in consequence of which no indications of teeth are anywhere visible. Possibly for the same reason no teeth are to be observed along the

margin of the lower jaw, nor lying free in the matrix, in case any had been broken away.

The mandibular ramus of the right side is well displayed, and the dentary is seen to have been retained in union with its fellow of the left side at the symphysis. The articulo-angular element is long, narrow in front, its superior border rising into a small median and a large posterior elevation, between which is a deep concavity; and its inferior border is nearly rectilinear. The superficial ornament of this piece has become well-nigh obliterated by weathering or abrasion, and of the two gular plates lying immediately underneath, nothing remains but an impression of their inner surfaces.

A notable peculiarity of the form under discussion consists in the arrangement of cheek-plates immediately in advance of the operculum. In all other Coelacanths, so far as known, two subequal postorbital plates are placed one above the other in the space between the orbit and operculum, their position being such as to exclude from contact with the latter the small triangular plate called "postmaxillary" by Huxley. The present species, however, has all three of these cheek-plates situated in vertical series, one overlapping the other from above downwards, and each of them overlapping the anterior border of the operculum. The lowermost cheek-plate, which corresponds to the so-called "postmaxillary" of Huxley, terminates below at a depth equal to that of the inferior border of the operculum, and its superficies covers the space immediately behind the inflected portion of the articulo-angular element of the lower jaw. Its antero-superior margin is apposed to the strongly arched and apparently semicircular suborbital element, of which only a small segment happens to have been preserved.

No indications are to be observed in the type specimen of a sclerotic ring, although one may be inferred to have been present as in other known Coelacanths. Neither is there any external indication of the presence of an ossified air-bladder, peculiar to members of this family. The caudal, anal, and pelvic fins are too imperfectly preserved for description, and the pectoral pair is entirely wanting. On the other hand the squamation is admirably displayed, especially in the posterior part of the trunk, where the fine longitudinal ridges of ganoine and concentric growth-lines are pyritized. The lateral line is rendered

conspicuous by a single large raised tubule of ganoine extending in a horizontal direction for nearly the total length of each scale in this row. The general appearance and some of the details of surface ornament of the type specimen are shown in the accompanying photographic illustration, which we owe to the kindness of Dr. Weller.

STUDIES FOR STUDENTS

RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS—*Concluded*

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PART III. RELATIONS OF CLIMATE TO STREAM TRANSPORTATION

Introduction.
Effects of stream transportation
Laboratory experiments and laws of river action.
Discussion of the data regarding transportation.
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Conglomerates and sandstones of marine, tectonic, and climatic origin.

INTRODUCTION

It has been seen that climate exerts a primary control, only subordinate to topography, upon the rate and character of erosion on the one hand and on the other upon the chemical, structural, and organic characteristics developed in subaerial sedimentation. Between erosion and sedimentation intervenes transportation and the questions arise: To what extent is the carrying power of rivers dependent upon climate? To what degree may the ordinary stratigraphic textural variations between succeeding strata of clay, sand, and gravel be due not only to shiftings of currents and tectonic movements, but to climatic variations as well?

In a general way the influence of climate upon erosion and upon deposition is readily recognized and upon closer examination the

effects, as previously shown, are seen to be largely distinct from those which the topographic conditions alone can produce. The determination of the lithologic characters due to the climatic conditions of erosion and of deposition constitute therefore two more or less independent lines of evidence as to the climatic conditions of origin. With transportation, however, it is different. Any particular capacity for transportation is conditioned upon topography as well as climate and any change in the size or quantity of the material transported, even if due to climatic change, may conceivably be due also either to a lateral shifting of river currents, if on a small scale, or to some crustal movement if the changes occur on a greater. The proof of the climatic change must, therefore, depend primarily upon the nature of the erosion and deposition, but it will be argued in the course of this article that great climatic changes may result in transportative variations of such magnitude that the results become the most pronounced of the three divisions of climatic influence upon fluviatile sedimentation, and have sometimes been ascribed to tectonic revolutions.

For these reasons (because of the dependence of the proof of the climatic change upon the initial and final conditions of sedimentation, and also because of the great importance of such climatic change upon the power of transportation, and the resulting coarseness and thickness of the formation) this middle factor in the conditions governing fluviatile sedimentation is treated the last of the three and not in what at first sight might appear to be its more logical position.

Effects of Stream Transportation

Laboratory experiments and laws of river action

The effect of transportation upon both the chemical and mechanical character of the material has been studied experimentally by Daubrée[1] who found upon submitting fresh and angular fragments of feldspar to prolonged trituration in the presence of distilled water that a very notable degree of decomposition was effected, as was shown by the presence in the water of silicate of potash which rendered the water alkaline.[2] The recent work of Cushman and Hubbard

[1] *Géologie expérimentale* (1879), pp. 248–88.

[2] *Op. cit.*, p. 271.

further shows that the decomposition occurring while undergoing abrasion due to movement in water takes place under exceptionally favorable circumstances, since if the initial film of decomposition is not continually removed the action of the water rapidly slows down;[1] and furthermore that the water alone, where the clogging films are continually removed, is well able thoroughly to decompose feldspar without the intervention of acid.[2] To the extent then to which mechanical abrasion occurs during river transportation decomposition is also favored and takes place at a vastly more rapid rate than in the normal weathering, which however persists through a far longer time while the material, owing to the lowering of the surface of erosion, is passing from the solid rock through the zone of soil. As to the mechanical effects:

In the series of experiments already referred to, Professor Daubrée made fragments of granite and quartz to slide over each other in a hollow cylinder partially filled with water, and rotating on its axis with a mean velocity of 0.80 to 1 metre in a second. He found that after the first 25 kilometres (about 15½ English miles) the angular fragemnts of granite had lost $\frac{4}{10}$ of their weight while in the same distance fragments already well rounded had not lost more than $\frac{1}{100}$ to $\frac{4}{100}$. The fragments rounded by this journey of 25 kilometres in a cylinder could not be distinguished either in form or in general aspect from the natural detritus of a river-bed. A second product of these experiments was an extremely fine impalpable mud, which remained suspended in the water several days after the cessation of the movement. During the production of this fine sediment, the water, even though cold, was found in a day or two to have acted chemically upon the granite fragments. After a journey of 160 kilometres, 3 kilogrammes (about 6½ lb. avoirdupois) yielded 3.3 grammes (about 50 grains) of soluble salts, consisting chiefly of silicate of potash. A third product was an extremely fine angular sand consisting almost wholly of quartz, with scarcely any feldspar, nearly the whole of the latter mineral having passed into the state of clay. The sand-grains, as they are continually pushed onward over each other upon the bottom of a river, become rounded as the larger pebbles do. But a limit is placed to this attrition by the size and specific gravity of the grains. As a rule, the smaller particles suffer proportionately less loss than the larger, since the friction on the bottom varies directly as the weight and therefore as the cube of the diameter, while the surface exposed to attrition varies as the square of the diameter. Mr. Sorby, in calling attention to this relation, remarks that a grain $\frac{1}{10}$ of an inch in diameter would be worn ten times as much as one $\frac{1}{100}$ of an inch in diameter, and

[1] "The Decomposition of the Feldspars," *U. S. Dept. of Agriculture, Office of Public Roads, Bull. No. 28*, 1907, p. 10.

[2] *Op. cit.*, p. 14.

a pebble 1 inch in diameter would be worn relatively more by being drifted a few hundred yards than a sand-grain $\frac{1}{1000}$ of an inch in diameter would be by being drifted for a hundred miles. So long as particles are borne along in suspension, they will not abrade each other, but remain angular. Professor Daubrée found that the milky tint of the Rhine at Strasburg in the months of July and August was due, not to mud, but to a fine angular sand (with grains about $\frac{1}{20}$ millimetre in diameter) which constitutes $\frac{2}{1000000}$ of the total weight of water. Yet this sand had travelled in a rapidly flowing, tumultuous river from the Swiss mountains, and had been tossed over waterfalls and rapids in its journey. He ascertained also that sand-grains with a mean diameter of $\frac{1}{10}$ mm. will float in feebly agitated water; so that all sand of finer grain must remain angular. The same observer noticed that sand composed of grains with a mean diameter of $\frac{1}{2}$ mm. and carried along by water moving at a rate of 1 metre per second is rounded, and loses about $\frac{1}{1000}$ of its weight in every kilometre travelled.[1]

It is to be concluded from these statements that long transportation by reducing the size of the coarser fragments and dissolving much of the soluble matter tends to cause the material derived from mountainous regions or sub-arid climates finally to approach the chemical and mechanical nature of the waste derived from topographically gentler or climatically more humid regions. This conclusion is confirmed by observation of the beds of rivers.

Walther shows that the large rivers carry very different sediment in the different portions of their courses.

In the upper course the deposits show a complete assemblage of all kinds of rocks and minerals found within the reach of the river system. In the middle course the pebbles disappear, but the sand is still of various kinds and contains besides the original constituents, contributions from the neighboring streams. The first materials to disappear are those minerals soluble or readily disintegrated, but hardness is also important in exercising a selective action, since in the rubbing of stones together the softer are soon destroyed. In the upper course of the Avisio a great quantity of limestone pebbles may be detected between blocks of porphyry and syenite. In the lower valley, however, the limestone pebbles completely disappear and the eruptive rocks increase relatively in number. Consequently in the erosion of a mountain consisting of a schistose formation containing secondary quartz veins the entire matrix may by the transportation be transformed into fine clay and the quartz pebbles alone remain as the indestructible residue.[2]

Walther further states that

it may be directly observed upon the bed of the Rhine that sand and small fragments will be moved forwards several decimeters while a larger fragment lying

[1] A. Geikie, *Textbook of Geology*, 1903, pp. 496, 497.

[2] Translated from *Einleitung in die Geologie* (1893–94), p. 758.

in the same place will only be moved a few centimeters and therefore remains behind. Such unceasingly repeated shoving must necessarily lead to a classification along the stream course of the rolled material according to its size. So soon as the volume of a stream is altered through climatic change or tectonic movement the boundaries are immediately shifted to which large or small pebbles, sand, or clay are carried and laid down.[1]

Chamberlin and Salisbury[2] state that:

Under certain circumstances, a stream may overload itself. Thus if a stream loaded with coarse detritus reaches a portion of its valley where fine material is accessible in abundance, some of the velocity which is helping to carry the coarse may be used in picking up and carrying the fine. This reduces the velocity and since the stream already had all the coarse material it could carry, reduction of velocity must result in deposition. It follows that when a stream fully loaded with coarse material picks up fine, it becomes overloaded, *so far as the coarse material is concerned*.

DISCUSSION OF THE DATA REGARDING RIVER TRANSPORTATION

Preliminary inductions.—From the preceding experiments, observations, and well-founded conclusions on the characteristics of river action the following inductions may be drawn.

First, the coarse material is not usually sufficiently strong or hard to stand long transportation by rivers, quartz, chert, or quartzite most effectively resisting the wear and alone being able to withstand transportation for distances of a hundred miles or more. It has sometimes been stated that the composition of a conglomerate of vein-quartz and quartzite pebbles indicates the erosion of a deeply and thoroughly decayed regolith, all but these constituents having been previously destroyed by weathering *in situ*. It is seen, however, that such a hypothesis is not necessary, since, if rivers existed sufficiently strong in current to sweep pebbles *long distances*, the quartz and quartzite would alone survive.

Second, rivers normally carry a large amount of finer material and a small amount of coarser, due to the disintegration and decomposition of the rock before it reaches the river, as well as the inherent weakness of the partially decomposed material which does reach the river in fragments. This loading up with fine material results in a lagging behind of the coarser more than if the fine was not present.

[1] *Op. cit.*, pp. 644, 645.

[2] *Geology* (1904), Vol. I, pp. 169, 170.

At times when for any reason, for example a climatic change, the fine material becomes deficient or the river volume becomes augmented, the river with the same grade may pick up the coarse material previously laid down and transport it with comparative rapidity to a lower portion of its course.

Third, Daubrée showed that upon revolving coarse and fine rock material in a barrel the coarser fragments, after being rounded, are reduced in size very slowly, so that a journey of several hundred miles would be required to reduce a pebble of 2 inches in diameter to 1 inch diameter. This may seem at first thought contradictory to the observations on river transportation, but the explanation is doubtless as follows:—The material which is of such a size that the current, which is already partially loaded with finer detritus, is just able to move it, is only moved with a fraction of the speed of the slightly smaller material. The result is that in being moved a mile down stream it may have moved ten or fifty miles relatively to the finer detritus. In so far as the rubbing and attrition are concerned, it has accomplished a journey many times the length of the actual distance moved. This lagging of the hardest coarse material under stable river conditions will be such that the added attrition due to the lagging is able to reduce it to that slightly smaller size which may be just handled by the slightly decreased velocity of the next lower portion of the river. With all but the hardest it appears, however, as previously stated, that the pebbles go to pieces faster than is called for by the necessities of transportation, so that in the lower portions of the valley there is an abnormal proportion of fine material—material which can be carried forward by a sluggish current—with the result that the condition for equilibrium is a flattened slope.

Fourth, the slope of a graded river is known to be in delicate adjustment between the volume of water, the quantity and fineness of load. These relations briefly stated are: (1) A more voluminous stream tends to flow down the same slope with greater velocity, the frictional resistence of the bed bearing a smaller ratio to the moving force. To remain in equilibrium upon such a slope the stream must carry more waste or coarser waste. Otherwise it will tend to load up its current by cutting down in the upper part of its course, building up in its lower until the grade is flattened, the velocity diminished and

equilibrium attained. The volume varies throughout the year and it is observed that in accordance with this principle by far the greater proportion of river detritus is moved in the seasons of flood. The same principle may be extended to apply to climatic cycles longer than that due to the revolution of the earth about the sun. (2) If through any climatic or tectonic change the forces of erosion are quickened and either a coarser or larger load of waste is poured into a stream of postulated constant volume, the stream must deposit the coarser of this material in place until the grade is steepened and the velocity consequently quickened sufficiently for transportation of a larger proportion. If the waste, on the contrary, becomes finer in grain or deficient in quantity, the stream responds by beginning to erode in its upper portions, tending to reach a new state of equilibrium by partially increasing its load and partly flattening its grade.

Relations of Stable Climates to Transportation

deductive conclusions with confirmatory illustrations

From the foregoing principles the relations, stated deductively, may be drawn between transportation and climate. The conclusions may then be tested by the examination of various regions which supply the requisite conditions. In sub-arid climates the streams in their upper portions have great temporary volumes and carrying power but the volume does not normally increase on the way. The result is that on escaping from the mountains the rivers in such climates are peculiarly liable to lay down a portion of their load, building piedmont slopes. The methods of erosion in an arid climate and the sudden tumultuous action of the streams result moreover in a large proportion of the deposit, consisting of a coarse and rather undecomposed waste, requiring relatively steep grades for its removal. The silt is swept farther out upon the flatter plains, while the clay and loess-like material may be carried to the front of the delta, provided the river waters are not absorbed on the way. The rivers of Argentina flowing eastward from the Andes furnish excellent examples, and to a lesser degree the rivers crossing the Great Plains of the United States. In both cases a condition of equilibrium is approached though never quite attained, between volume and waste upon a slope

which descends several thousand feet in a distance of several hundred miles.

The streams of a rainy climate on the other hand have greater carrying power over their lower and flatter courses, owing to the continually augmented volume with distance from source. The material carried is also more largely fine-grained than in the case of the sub-arid climate, a considerable portion consisting of true clay. There is consequently less tendency to build piedmont slopes and more to deliver the waste to the delta and the sea. In warm humid climates thoroughly oxidized and leached clays form a maximum percentage in the land waste, giving a river grade of maximum flatness after escaping from the mountains. The Amazon furnishes an excellent example, its bed being but 370 feet in elevation at the junction of the Marañon and Ucayali at a distance of about 1,800 miles from the ocean. The grade of the Amazon is doubtless, however, somewhat flatter and lower in its middle course than is called for by the present relations of volume and waste, since it is characterized by braided streams, distributaries, and shallow lakes. In cold rainy climates frost becomes a powerful disintegrating agent in mountainous regions, developing with great rapidity vertical cliffs skirted by coarse talus slopes and accentuating during the early portion of the cycle the steepness and roughness characteristic of such regions. The waste supplied to the rivers is coarser than that from a warmer region possessing the same broad topographic features, and the river consequently must flow on a somewhat steeper grade for the same volumetric relation of river water to sediment.

Effects of Varying Climates upon Transportation

In short streams of steep grade, such as those draining from the coast chains of California toward the ocean; or in longer ones of low grade, such as most of those of the Atlantic coast of the United States, the deposits of alluvium under all circumstances are largely marine and the chief effect of a change of climate upon the sedimentation is due to the resultant changes in the rate and kind of erosion rather than changes in the transportation. As pointed out under the subject of *the relation of topography and climate to erosion* this alone should lead to well marked differences in the sediment. In the larger

and longer river systems, however, especially those rising in mountain regions, influences of another character come in, of even greater stratigraphic importance.

CLIMATIC CHANGE FROM SEMI-ARID TO RAINY

To appreciate the maximum possible results imagine semi-arid alluvial plains such as the Pampas of Argentina and the High Plains of the United States to become the seats of a markedly rainy climate such as that of the Amazon basin. The rivers, constantly swelling in volume from additional drainage in crossing the inclined plains will erode the unconsolidated or semi-consolidated sands and gravels with immense rapidity, possibly sweeping such deposits entirely away and channeling into the rock formations below. In the case of the slopes cited from 500 to 1,000 feet of deposits could on a conservative estimate be swept off from large areas before the river currents would become sufficiently sluggish in consequence of the lowered grade of their middle courses to cease from the vigorous erosion. In the meantime over the headwaters erosion would not have increased in any such measure and might in some instances actually decrease in rate, since the vegetation if more luxuriant would hold the soil to the slopes on the one hand and on the other the corrasion of stream channels is measured by the volume of the occasional heavy floods rather than by the quantity of the constant rains. The increased fineness of the mountain waste, even if the same in quantity, and its less ratio to the greater volume of water will give the rivers still greater powers of erosion after escaping from the mountains.

In the normal topographic cycle the rivers which in their youthful stage build up piedmont slopes will in maturity begin to trench and remove them, owing to the decreased height in the region of the headwaters and the lessened rate of erosion. A strong climatic change from semi-arid to pluvial will therefore work with the normal topographic cycle and the results as recorded in the sedimentation over the lower portion of the system will be proportionately more marked than if the climatic change acted alone.

In this rapid erosion the coarse material constituting the piedmont slope will not be slowly rolled forward while being worn down *pari passu* by the friction of the smaller particles swept past, but will be

carried forward rapidly whenever reached by the tumultuous currents. It will therefore have moved relatively to the adjacent finer material but little farther than the actual distance; whereas, as previously pointed out, the coarser material usually moves relatively many times farther than the finer. Not only, therefore, will the final region of deposit undergo a sudden increase in sedimentation which may be called a veritable flood of waste, but it will be of phenomenal coarseness compared to that which preceded and that which will come after, the preceding sediment being fine in the delta region on account of the small carrying power of the rivers of the semi-arid plains; the succeeding sediment being fine because of the graded character of the mountain slopes and the more decomposed nature of the waste which they give to the streams in a time of more pluvial climate. The coarser material deposited on the delta region will, however, be finer than that previously deposited on the piedmont slopes since attrition and wear are inevitable during transportation. Such a climatic change from subarid to rainy will thus be marked by a shifting of the stored waste of the earlier epoch from the middle to the lowest portion of the river system. If it be assumed that the area of deposition in the second case is no larger than in the first, the amount will form a deposit on the average of equal thickness to the depth of the erosion in the piedmont plains. Thus it is within the limits of past possibilities that widespread sand or conglomerate formations intercalated between others of markedly different nature should be formed upon delta surfaces or over the bottoms of shallow seas, as the result of a rapid and profound climatic change. Such formations in the regions of their greater coarseness would be remarkably clean from clay and where reaching a maximum development might be several hundred or even a thousand feet in thickness. This possibility will become a probability in proportion as such arenaceous or conglomeratic formations are widespread, dissociated from the other evidences of origin through crustal movement, and correlated on other lines of evidence with climatic changes of the proper nature.

The most favorable period for the testing of these deductive statements is the Pleistocene, since the deposits are still preserved at the surface, they can be traced to their sources in the regions of erosion and great climatic oscillations are known to have taken place. The

complication, however, is that in many regions profound crustal movements are also known to have occurred. This correlation of climate with erosion and aggradation has been made by W. D. Johnson to explain the oscillations between stream-cutting and stream-building of the Great Plains region during the Quaternary. He notes that:

> There are two possible disturbing influences which may result in transformation of the gradation plane—deformation and change of climate. But it is not necessary, in order to account for change in behavior of the traversing streams, to appeal to deformation. A sufficient cause may be looked for in change of climate. There is record of erosion, with reversal to deposition and rebuilding, and reversal again finally to erosion, and there is reason for believing that this series of interruptions of the gradation cycle was an effect of climatic oscillation rather than of earth movement. The date of the building of the great débris sheet, so far as included fossil remains would seem to determine it, might range anywhere from middle Tertiary to early Pleistocene. However, the beginning of the final and present degradation stage, during which the smoothness of the Great Plains has been in large part destroyed and their surface lowered, with exception of the sod-covered plateaus of the central zone, doubtless dates from the opening of that period of climatic oscillations in the Pleistocene which, in the Great Basin region of Utah and Nevada, gave rise to repeated floodings of large areas and the creation of lakes. Indeed, it is not unlikely that the grading of certain of the minor plateau surfaces of the High Plains, which stand appreciably below the general level, is to be correlated with the several returns in the Great Basin to severe desert conditions during this period, which also are plainly recorded among the old lake evidences.[1]

In investigations of Pleistocene geology great attention is properly paid to the surface form, and in fluviatile and pluvial work erosion is more studied than sedimentation. In more distant geological times, however, it is the record of the deposits which must be almost entirely the basis of study. For such purposes, therefore, the relations of erosion and aggradation within the High Plains are not of so much final importance as the question, What was the nature of the deposit made by the erosion of the sands and gravels of the High Plains during times of wetter and colder climate? The suggested but not demonstrated answer is, that the landward edge of the corresponding deposit appears to be the Orange Sand Delta of Hilgard, now known as a Mississippian portion of the Lafayette formation.

[1] The High Plains and Their Utilization. *21st Ann. Rept.*, U. S. Geol. Survey, Pt. IV, 1901, p. 626, 628–30.

As shown by Hilgard,[1] this is a widespread, flood-made formation, extending along the great valley of the continent, the Mississippi, south of its junction with the Missouri and on the Gulf Coast reaching from Mobile Bay in Alabama to the Sabine River on the borders of Texas. The formation consists in large part of orange, rust colored, but sometimes purplish, white, or variegated sand, consisting almost entirely of quartz grains much rounded and smoothly polished, and very commonly encrusted with the rusty pigment. Near the great river channels, notably that of the Mississippi on either side, on the Tombigbee and Tennessee, as well as on the Sabine there is a steady increase of gravel. The beds are irregularly stratified, sometimes structureless for 20 feet of thickness, but have generally the flow-and-plunge structure. Hilgard considers that the formation as a whole is the outcome of fresh water in the state of violent flow. The "Orange Sand" increases in thickness toward the Gulf. In an artesian well near the Calcasieu River, 200 miles west of New Orleans, beds referred to the Lafayette are found to extend to a depth of 450 feet, beneath 160 feet of clay of the Port Hudson group; and at New Orleans the gravels have been found by borings to extend to 760 feet below the level of the sea. Hilgard showed that it overlaid the Grand Gulf beds and was in its turn covered by the Port Hudson or Columbia. He considers that it is latest Tertiary or earliest Quaternary, and he correlates this increase of fresh-water action with the melting and retreat of the first glacial stage. Chamberlin and Salisbury consider, however, that glacio-fluvial work is not concerned in the origin of this Mississippi portion, since upon careful search neither was able to find any pebbles referable to glacial action,[2] this origin being restricted to the Natchez formation which overlies it.[3] These authors favor the hypothesis that the Appalachian portions at least were developed by successive shiftings of river deposits toward the sea during Pliocene upward bowing of the partially developed Tertiary peneplain in the region of the Appalachians, but

[1] "The Age and Origin of the Lafayette Formation," *Amer. Journal of Science*, Vol. XLIII (1892), pp. 389–402.

[2] T. C. Chamberlin, "Some Additional Evidences Bearing on the Interval between the Glacial Epochs," *Bulletin of the Geological Society of America*, Vol. I, 1890, p. 470.

[3] *Geology*, Vol. III (1906), p. 308.

also recognize the influence which changes in precipitation and temperature may have had upon the rate of erosion.[1] Such shiftings of the gravels as were produced by the bowing would result in a progressively younger age of deposits found in going down the streams from the axis of bowing and therefore the Lafayette deposits of separated districts may not be of strictly contemporaneous origin.

As facts which have a bearing upon the relative influences of tectonic and climatic causes, it may be pointed out that according to Hershey erosion following a Pliocene uplift opened out basin valleys in the Ozark Highland from 75 to 100 and even 300 feet below the main Tertiary peneplain. These valleys are *floored* with Lafayette gravels which Hershey states represent the *end* (italics introduced) of deposition of the Lafayette formation, but the evidence for the latter statement is not given.[2] Following the development of these valleys another uplift, reaching in southern Missouri to at least several hundred feet, enabled the streams to excavate the inner canyon valleys of Ozarkian age. In this locality, then, the Lafayette appears to have been deposited at a time of crustal stability between two stages of uplift. While its presence could be explained by either a tectonic or climatic hypothesis, the latter is perhaps the easier, since at a time of crustal stability a climatic instability, by varying the ratio of erosion to transportation, could make itself most readily felt; now by an excess of erosion depositing material near the headwaters and steepening the grade, again by an excess of transporting power shifting the same to a lower portion of its course. Such a climatic instability marked the close of the Tertiary and increased in intensity until it resulted in the tremendous climatic reversals from glacial to interglacial intervals which marked the Pleistocene.

The chief criticisms which may be brought against this view lie in the entire lack of glacial material in the composition of the Lafayette formation and the good evidence of nearly related crustal movements of greater or lesser magnitude which affected the continent at about this time. But in continental interiors it is only land warpings

[1] *Op. cit.*, pp. 305–8.

[2] "Peneplains of the Ozark Highland," *American Geologist*, Vol XXVII, 1901, pp. 33, 41.

which can directly influence the rate of erosion unless the land uplift is sufficiently prolonged for the streams to steepen their grades from the sea backward to the headwaters, while glacial material would be absent until the increasing ice sheets actually invaded the headwaters of the streams building the formations. In the present connection it is desired to bring into more prominence the climatic factor, but without presuming to decide upon the relative importance in this case of the tectonic and climatic causes, as a final decision must be based upon broad field-work with both hypotheses in mind. It may be pointed out, however, that this quickening in erosion and transportation appears to have been very extensive over the United States and has been ascribed to a time of cool moist climate by a number of writers from several lines of evidence, such as the included bog deposits;[1] but there is also a suggestion by Chamberlin and Salisbury, from the oxidized character of the formation, that there were effective dry seasons.[2] This might simply imply, however, a more diversified climate while at the same time more rainy. A somewhat similar paradox is pointed out by Chamberlin and Salisbury in regard to the relationship of the loess to the Iowan ice invasion and the absence of gravel trains, "both phenomena, perhaps, implying aridity, strange as that may seem in a glacial epoch."[3]

In view of the diversity of opinion upon the origin, age, and extent of the Lafayette, an opinion in the present connection should be expressed with caution. It would seem, however, that the great development of sand and gravel on the margins of the Gulf and to a lesser extent up the Mississippi River corresponds with such an erosion of piedmont sands and gravels as is seen to have taken place from the High Plains. In each case there is the added volume of water required in the one region for erosion, in the other for the transportation of such material. Both events are known to have occurred near the close of the Tertiary or early opening of the Quaternary, and by correlating the two the necessity is avoided, either of assigning the flood waters to the melting and retreat of the ice sheet, or to a greater southward slope to the Mississippi Valley, or to local tilting of the High Plains in order to rejuvenate erosion. The climatic

[1] Hilgard, *op. cit.*, p. 401.

[2] *Op. cit.*, Vol. III, p. 304.

[3] *Op. cit.*, Vol. III, p. 412.

change which is known to have taken place at about that time seems a sufficient hypothesis, and renders the other necessary only where warping or tilting of previous base levels can be demonstrated. In graded rivers of considerable volume a slight increase of volume, by producing erosion along the whole stream course would seem competent to sweep sand and gravel to great distances, which previously could not be transported along the bottom, resulting in the deposit of hundreds of feet of gravels at New Orleans whither now the Mississippi carries chiefly clay and in its channel nothing coarser than sand.[1]

On the other hand, W. J. McGee points out that the Lafayette bordering the continent was laid down during an epoch of land subsidence and that these Quaternary gravels may therefore be reworked Lafayette gravels, owing to a Quaternary land elevation and rapid erosion in the lower portions of the rivers.[2] To account for the original Lafayette gravels of the lower Mississippi, carried seaward during a low stand of the land, a hypothesis of climatic change appears to the present writer to apply most readily. If the Quaternary gravels consist, however, of a redeposition during a low stand of the sea and not during a local and progressive subsidence of the lower Mississippi, then such a fluctuating sea level is sufficient to account for a Quaternary redeposition without invoking as a further aid a climatic cause, even if such may have been also in operation.

Irrespective as to whether or not, however, the orange sand of the Mississippi Valley is the formation which represents in part the prod-

[1] Since the above was written two further communications have appeared bearing upon the age and mode of origin of the "Lafayette beds" of Louisiana. G. D. Harris records the existence of sands, clays, and gravels, the latter of typical Lafayette type, extending to a depth of at least 1,500 feet; while a Quaternary molluscan fauna extends down to about 2,000 feet. The well records thus seem to indicate that the seaward continuation of the gravels in the central portion of Louisiana as well as in those states to the east and west are rather Quaternary than Pliocene. It would seem, then, that Hilgard's views as to the contemporaneousness and interrelationship of the coarse "Orange sands" in the south and the ice sheets in the north may prove correct in spite of the fact that certain "Lafayette" gravels are said to lie beneath glacial till farther north. (G. D. Harris, "Note on the 'Lafayette Beds' of Louisiana," *Science*, N. S., Vol. XXVII, 1908, p. 351.)

[2] *Science*, N. S., Vol. XXVII, 1908, p. 472.

uct of the erosion of the High Plains, the fact still remains that the erosion was concentrated into certain stages and that somewhere sediments of increased volume and coarser nature must have been deposited.

The same principles may be applied to the more distant past. Where the sediments by the chemical conditions of erosion and deposition give evidence of profound climatic change, such for instance as ushers in glacial periods, equally profound textural changes in regions beyond the reach of glaciation, whereby sand or even pebbles were swept to the delta regions or the seas beyond, may properly be ascribed to the change of climate and do not necessarily require any crustal movement for their origin, though they may be complicated by the presence of such movements. In this way periods of glaciation may make their existence felt far beyond the actual limits of the ice invasion. It is thought by the writer that the Pottsville conglomerate or Millstone grit which so commonly underlies the coal measures of the eastern United States and western Europe, sharply separating the Carboniferous from the sub-Carboniferous of those regions, owes its origin primarily to such climatic change.

CLIMATIC CHANGE FROM RAINY TO SEMI-ARID

Having given the previous analytical discussion, the reverse side of the problem may more briefly be stated. At a time of marked change from rainy to semi-arid the waste poured into the upper part of the streams may be rapidly increased in amount and in coarseness, owing to less efficient vegetation and more concentrated floods. In crossing the plains of the middle course, however, the rivers will diminish instead of gaining in volume. They will find their previous valleys much below grade with the result that a larger proportion of river sediment will be deposited upon the piedmont slopes than would even be the case under the same climate after the river grades had acquired slopes in equilibrium with the conditions. An accentuated deficiency of sediment will consequently be noted at the terminus of the river system. The stratigraphic effect of such a climatic change will depend, as in the previous instance, upon the quickness and amount of the change, the distance of the headwaters from the delta, and the height of the source. These factors measure the difference

in angle between the stable grades under the two conditions and the volume of sediments required to be shifted to cause one grade to pass into the other.

These deductive statements find perhaps their best illustration in Persia, a region which, while so arid as to have no outflowing drainage, yet is known from several lines of evidence to have undergone marked climatic desiccation during historical times. Blanford in 1873 called attention to the superficial gravels, sands, and clays of the valleys and deserts of Persia.[1] He notes that the margins of the valleys usually consist of a long slope composed of gravel and bowlders, and with a surface inclination of from 1° to 3°. Such slopes often extend for a distance of from 5 to 10 miles from the base of the hills bounding the plains, the difference in level between the top and bottom of the incline being frequently from 1000 to 2000 feet, or even more. The peculiarity of these slopes in Persia consists in their great breadth and in the enormous mass of detrital deposits which they contain. In the central portions of the valleys the surface usually consists of very fine, pale-colored, rather sandy earth, not unfrequently impregnated with salts.[2] In discussing the origin of these gravel deposits Blanford notes that it is usually the drier tracts in which accumulations of gravel attain their greatest dimensions while

> Toward Shiráz the slopes of loose detritus on the sides of valleys are much less extensive, and in places, as in the valley of the Bandamir, above Persepolis, entirely wanting,the flat alluvium of the valley extending to the limestone ranges on each side. This may be due to a former extension of the existing salt lakes far into the valleys of Shiráz and Persepolis, and to the deposition of silt in the lakes in sufficient quantities to conceal any accumulation of detritus near the side of the valley; but there appeared to me to be a similar deficiency of gravel slopes on the sides of the higher valleys containing running streams, and I am much inclined to believe that their absence is connected with the heavier rainfall. . . . .
>
> *Probable origin of gravel accumulations.*—This gives a clue to the origin of these immense spreads of recent or sub-recent deposits; and in connection with the last observations I may mention that usually, in Southern Asia, so far as I have seen, it is the drier tracts in which accumulations of gravel attain their greatest dimensions. . . . . Bearing in mind that all accumulations of detrital matter

[1] W. T. Blanford, "On the Nature and Probable Origin of the Superficial Deposits in the Valleys and Deserts of Central Persia," *Quarterly Journal of the Geological Society of London*, Vol. XXIX, 1873, pp. 493, 503.

[2] *Loc. cit.*, pp. 495, 496.

are due to arrest of motion, whether partial or total, in the transporting agent, we can easily understand that the rainfall on the Persian hills may suffice to wash down as far as the sides of the valleys those fragments which, by chemical agency or the action of frost, are loosened from the hill-sides; but when once the momentum given by the steepness of the incline is at an end, the quantity of water drained from the surface is insufficient to transport the débris to a lower level; all that it can do is to leave the detritus in a long slope, the surface of which is arranged by the wash of rain.[1]

These views receive further support from the observations of Medlicott and Blanford on the relations to the rainfall of the piedmont gravels which face the south slopes of the Himalayas. In this connection they state:

Bhábar is the slope of gravel along the foot of the Himalayas. Compared with the slopes in the dry regions of Central Asia, Tibet, Turkestan, Persia, etc., the gravel deposits at the foot of the great Indian ranges are insignificant, the difference in height between the top and bottom of the slope nowhere exceeding 1,000 feet. . . . . This difference is probably partly due to the much greater rainfall in India, and to streams being consequently able to carry away a much larger proportion of the detritus washed from the surface of the hills, partly also to the circumstance that the rocks in the lower regions of the hills are not subjected to the loosening effects of frost.

The *bhábar* slope of gravel along the foot of the Himalayas, although evidently of comparatively recent formation, has frequently, to the eastward, been cut into terraces by the streams from the hills. This is a necessary consequence of the streams cutting deeper channels in the rocks of the hilly ground. It is curious to note, however, that to the westward the *bhábar* is being raised instead of being cut through by streams. The difference is not improbably due to the much greater rainfall to the eastward, and to the streams being consequently able to carry away the gravel as they cut back their bed in the rock, whereas weaker streams are prevented from cutting back their channels by their inability to wash away the gravel they have already deposited. It may be, too, that from local causes the gravels to the westward are more easily percolated by water and therefore streams, instead of carrying away the *bhábar* deposits, sink into them; but, judging from the enormous development of the gravel slopes in regions of small rainfall, it is more probable that the first hypothesis is correct.[2]

In conclusion on this topic it is to be pointed out and emphasized that *the climatic significance of gravel deposits on piedmont slopes is precisely opposite in character to the same when found on the delta plain*. Climatic inferences cannot therefore be safely made unless,

[1] *Loc. cit.*, p. 498.

[2] Medlicott and Blanford, *Geology of India* (1879), Part I, pp. 403, 412, 413.

after the exclusion of the possibility of a tectonic origin, the synchronous relations of erosion and deposition are investigated for the three portions of the river system and the relative location of portions undergoing degradation and aggradation are determined. Even by those who have recognized the frequent climatic origin of changes in river grade the necessity of clearly stating these relations seems to have escaped attention.

CLIMATIC CHANGES DUE CHIEFLY TO TEMPERATURE

In the discussion of the relations of climate to erosion the characteristics of weathering in hot and cold climates were discussed. Under the present topic of the relations of climate to transportation it need only be said that a cooler climate, by producing less evaporation, will alone serve to increase the percentage run-off of the river systems. A change from a temperate to a rigorous climate tends, therefore, not only to increase the amount of waste given to the river in its upper portion, but will result to some extent in an increase of the coarseness and quantity of material carried through to the delta. A change from a temperate to a hot climate on the other hand will tend to diminish the percentage of run-off, and with it the coarseness of the waste which is transported. Provided that the waste becomes finer, however, from greater decomposition, the quantity carried by the stream may not be decreased. At the headwaters the amount of waste is presumably increased by more intense insolation or more rapid decomposition over the conditions of a milder climate, tending to build piedmont slopes.

Oscillations to climatic extremes of any sort may, therefore, be considered to accelerate rock destruction, but only oscillations toward a more concentrated or voluminous rainfall or toward marked coolness of climate will result over the regions of distant deltas and epicontinental seas, in an increased quantity or coarseness of deposit.

CONCLUSION

CONGLOMERATES AND SANDSTONES OF MARINE, TECTONIC, AND CLIMATIC ORIGIN

Summing up the preceding discussion it is to be concluded that conglomerates and sandstone formations intercalated between others of different nature may be due to three distinct causes:

First, marine conglomerates and sandstones.—Due to marine planation and transportation, enabled to reach wide horizontal extent over shallow seas through crustal movements shifting the zone of wave and current action.

Second, tectonic conglomerates and sandstones.—Due to subaerial erosion owing to a steepening of the river slopes, either from mountain making, crustal warping, or subsidence of the ocean level.

Third, climatic conglomerates and sandstones.—Due to climatic change without necessarily any new accompanying crustal deformation. In distant periods, when the change has been of such a nature that the accumulations of gravel and sand were local and deposited near the sources of the material there is less probability, on account of the smaller original area and its higher level of deposition, of such being observed, or separated and distinguished from deposits of purely tectonic origin made by erosion during a period of stable climate. When the change was of such a nature, however, either to a more rainy or colder climate, that the pebbly or arenaceous detritus was swept forward for hundreds of miles from previous sources of erosion and accumulation, formations which may be described as great sandstone plates must have resulted, intercalated between others of a finer and more argillaceous nature, conspicuous in the geologic column both from their areal extent and their physical contrast; a contrast due to the climatic change operating in the region of deposition as well as influencing the character of the transportation. Applying this principle to the geologic past, if the sections made by nature across the deposits of ancient deltas or shallow seas indicate a periodical fluctuation in kind and in coarseness of sediment, and if such variations can be correlated *on other grounds* with climatic changes of the proper nature, it is the simpler hypothesis to hold that the latter and not repeated synchronous deformations have been the causes of the changes in sedimentation.

In the history of geologic science it is to be noted that to marine action was once ascribed the greater part of planation of the land and the formation of conglomerates and sandstones from the débris; a natural stage in geologic theory, when it is considered that the earth science developed most largely upon the northwestern shores of Europe where there is a maximum of coast line, of coastal erosion, and of shallow sea. An awakened appreciation, however, by the following

generation, of the importance of repeated epeirogenic and orogenic movements in maintaining the land surface and supplying, through subaerial erosion and fluviatile transportation, the materials of the sedimentary rocks, has led to the recognition of the tectonic causes of many of the changes which distinguish and separate the series of sedimentary formations. But it is probable that tectonic causes have been too freely ascribed in explanation of the origin of formation differences in so far as a possible climatic origin has not been held in mind. An inspection of geological literature indicates that, although the possibility of such climatic causes has been increasingly appreciated in recent years by certain investigators, yet in general, geologists have not considered the possible effects of climatic changes when seeking the causes of variations in strata, especially such as are due to size of particles. Usually the climatic factor is only regarded when considering the characteristics of the fossil fauna and flora or when deposits are present of such obvious nature as those of salt and gypsum or the products of glacial action. It is desired here to call attention to climatic change as a cause of sedimentary variation in detrital deposits of co-ordinate importance with marine planation and crustal movement. In order to discriminate correctly between the three classes of deposits where occurring in the geologic record criteria must be employed for their separation, though it is doubtless true that a correct evaluation of the factors entering into the formation of many deposits may never be achieved.

It is natural that the influence of climatic change in producing shiftings of the sedimentary facies should be the last kind of action to reach a true appreciation. Marine and tectonic conglomerates and sandstones are now observed in the making, but the *shifting* of these regions of deposition through climatic changes and by which climatic deposits as distinct from the others are to be determined is only evident on comparing the present relations of erosion and deposition with those occurring in the recent past under the same tectonic but different climatic conditions.

In conclusion something may be said of the relations of the three classes of deposits to each other. The geologic environment of a land consists of three fundamental factors: the relations of land and sea, the relations of topography, and the relations of climate. Each of these may be practically stable for a time, being subject to minor oscillations

only, but ultimately great changes take place separating earth history into its periods and eras and giving to each an individual character.

Marine conglomerates and sandstones, but especially conglomerates restricted to those whose material is obtained and sorted by the waves and transported by bottom currents, where widely developed and intercalated between unlike formations, are indicative of broad movements of the beach line; that is, of the changing relations of land and sea.

Tectonic conglomerates and sandstones are of subaerial origin and result from vertical earth movements, ultimately from either horizontal or vertical forces. To separate them sharply from climatic conglomerates and sandstones, the climate is supposed to be unchanging during the progress of the following erosion.

Climatic conglomerates and sandstones are also of subaerial and fluviatile origin, but owe their contrasts with the superior and inferior formations to climatic and not tectonic changes. To separate them clearly from deposits of tectonic origin earth movements must be supposed quiescent while climatic variations of greater or less degree are supposed to occur, resulting in changes of the sedimentary facies and in shiftings of the regions of deposit of that land waste which arises primarily through the contest of tectonic and atmospheric forces. Where the climatic changes have been great and rapid, the nature of the erosion may be so changed and the regions of deposit so widely shifted that these climatic variations may be the cause of the most striking differences between formations. Climatic conglomerates and sandstones are here made distinct and independent from those of tectonic origin by the taxonomic elevation of the *shifting location* of deposits (in space) to co-ordinate importance with *intermittent uplift* and resulting pulses of erosion (in time).

Changes in volume of ocean waters, earth movements, and atmospheric activities are the three mixed and fundamental causes by which the three classes of deposits become possible, but the records which they embody are largely distinct and independent. By separating conglomerates and sandstones into these three classes the sedimentary rocks, therefore, present a threefold record, the marine conglomerates giving that of the variable relations of land and sea; the tectonic conglomerates, the record of variable vertical uplifts; the climatic conglomerates, the record of variable temperature and rainfall.

Reviews

La science séismologique: les tremblements de terre. By F. de Montessus de Ballore, with an Introduction by Eduard Suess. Paris: Armand Colin, 1907. Pp. 579, 222 figures, maps, and plates.

In the month of January, 1906, there came from the press of Armand Colin in Paris an illustrated monograph of some five hundred pages written by the Count de Montessus de Ballore and bearing the title, *Les tremblements de terre: géographie séismologique.* This important work grew out of almost a lifetime of labor and has laid the foundations for a branch of seismological science well described in the subtitle of the work, Seismic Geography. The present volume, which is uniform in style with and somewhat larger than its forerunner, was issued in December, 1907, or less than two years subsequent to the appearance of the *Seismic Geography.*

The earlier volume discussed the distribution upon the earth's surface of all recorded earthquake shocks, of which no less than 170,000 were brought under consideration. Not only were these shocks graded and compared by earthquake provinces, but within each province the distribution of seismicity was studied by a newly derived method, and maps were prepared on which all places which had been visited by important shocks were placed in relation with one another. Further, the geological structure of each district was inquired into and the relation of the so-called epicenters to lines of fracture and faulting was pointed out.

The new volume is a treatise upon seismology in all its aspects, and is at once the most comprehensive and the most authoritative work upon the subject which has yet appeared. Dr. de Montessus is an omniverous and very careful reader of the literature of the science, and in addition to the three principal languages of the scientific world, he has brought to his aid a reading knowledge of a number of others, notably Italian, Spanish, and Russian. It is to this fact as well as to the long period during which he has been collecting the data that the comprehensiveness and the broad perspective of the work are to be ascribed. If the data of seismology have been long in the assembling, the advance of the science is all comprised within a notably brief and recent period. The present is, in consequence, a time of transition as regards both the methods of study and the

fundamental theories of seismology. *Seismological Science* is for all these reasons a work to which the future student will often be compelled to refer.

The centrum or volcanic theory of earthquakes which has so long held the stage is here relegated to the lumber-room of the science, and for it is substituted the conception that earth shocks are directly due to a mutual adjustment of sections ("compartments") of the earth's crust which are moved individually like blocks between the faults which bound them. This new view-point is made the keynote of the entire work, and again and again in the pages of *Seismological Science* it is pointed out how facts before unintelligible or in direct conflict with others are now for the first time explained and brought into harmony. To this view Professor Suess has given his indorsement in the preface, where he has used the following language:

> Seismic studies have passed by the same halting-places as the other branches of our knowledge. And if, in order to reach some summit of our great mountain chains, the Alpinist crouches upon a rock, not alone for the purpose of resting but that he may launch himself to greater heights after he has regained his breath; so seismology started out from a simple and perfectly schematic conception, that of the *epicenter*, the point of the earth's surface from which the earthquake seemed to emanate, and all efforts were directed toward fixing the position of this ideal geometric point; today seismology rejects this conception as too much simplified and valuable only for the shocks due to volcanic explosions, in order that it may rise to that of mutual adjustments within the design of the terrestrial marquetry.

De Montessus' classification of earthquakes is into *macroseisms* or sensible earthquakes, *microseisms* or unfelt earthquakes registered by instruments, and *megaseisms* or destructive earthquakes; and each of these is treated in a separate part of the work. Considerable confusion now exists as to the interpretation of the terms macroseisms and microseisms, and the reviewer is of the opinion that Milne's usage, making macroseisms the more destructive earthquakes and microseisms the weaker shocks, is better supported by derivation and practicability alike, though the other view has perhaps the larger following. In the Count's usage a microseism is a megaseism examined at a distance. The term microseism as applied by de Montessus is also likely to be further confused with those pulsational movements of pendulums which arise from causes other than those which produce earthquakes.

It is impossible in a brief review like the present to discuss the many subjects which are treated in this most important monograph. It will be

interesting to recall that de Montessus' interest in earthquakes was first awakened when he was a resident in Central America giving instruction in military science. The greater part of his work has, however, been accomplished in France as a major of artillery, for much of the time upon recruiting service. The last proofs of the present work he revised in South America, where he now directs the seismological service of the Republic of Chili. W. H. H.

Research in China. Vol. I, Pt. I: Descriptive Topography and Geology. By BAILEY WILLIS, ELIOT BLACKWELDER, AND R. H. SARGENT. Vol. I, Pt. II: Petrography and Zoölogy. By ELIOT BLACKWELDER; Syllabary of Chinese Sounds, by FRIEDRICH HIRTH. Vol. II: Systematic Geology. By BAILEY WILLIS; Atlas, by R. H. SARGENT. Washington, D. C.: Carnegie Institution, 1907.

These sumptuous volumes constitute a monumental contribution to Asiatic geology. They are signal productions not only in their substance and form, but in the fact that they are a gift of productive industry to progressive science, and a tribute of one of the newest phases of civilization to one of the oldest. They give expression also to a departure from inherited methods in that, though the work was circumscribed by limitations of time and means, and confessedly but expeditional, it was given a high degree of maturity so far as it went, with the definite expectation that other mature work, by some competent organization, will be duly fitted on to it on either hand. The territory attempted was mapped topographically as well as geologically, and both with a degree of fidelity, so far as one can judge, comparable to that of an official survey of the better order. The limitations of any survey made by such an expedition are necessarily great, but there is ground to believe that, in this case, these are chiefly limitations of area merely.

The ground covered embraced a selected tract in the province of Shantung in northeastern China, chosen because of its Cambro-Ordovician terranes, and a strip, of rather wandering course, reaching from the province of Chili in north-central China westward and southward and then southeastward, through the provinces of Shan-si, Shen-si, and Hu-peï, terminating at the lower cañon of the Yang-tsï-kiang. The formations involved range through the whole geological column, but the more notable phenomena brought to attention are those of the Cambro-Ordovician, the Siluro-Devonian, the Carboniferous, and the Tertiary-Quaternary. These are treated descriptively in Vol. I, and systematically and philosophically

in Vol. II. The descriptive contributions of Blackwelder are an important factor of the investigation and give evidence at once of fidelity and skill. The systematic and philosophic treatment by Willis presents in lucid form the larger deductions of the investigation, embracing at once the stratigraphic, the physiographic, and the dynamic. Although the order selected for presentation in these volumes is the natural and logical one, some will find it serviceable to read the systematic summation and the salient conclusions of Vol. II first and seek the details on which they are based afterward.

The previous work, of Richthofen, Pumpelly, and others have given us some familiarity with the stratigraphic series of central China, and have thus taken the flavor of freshness from some of the important lines of this research, but new features of critical interest have been brought forth by this investigation, more, indeed, than could have been anticipated, and some of these are distinct surprises. The analysis of the deformations by physiographic, as well as stratigraphic methods, and the determination of geological stages by the former method are among the most notable contributions. These cannot be reviewed in detail here, nor would it be best if practicable, since they can be appreciated at their full value only by reading at length the elegant verbal and graphic expositions which they have received at the hands of an artist at once with pen, pencil, and camera.

Perhaps the most startling and, in many respects, the most significant of the results of the investigation was the discovery, on the Yang-tsĭ-kiang, in about the latitude of New Orleans, of a thick glacial deposit lying below the trilobite horizon of the Lower Cambrian. This discovery, supported by evidences of similar formations at approximately the same horizons, as it would appear, in distant parts of the earth, added to Coleman's recent determination of a still earlier glacial formation at the base of the Huronian in North America, and supported by the general deductions from cosmogonic and physical data that have recently been advanced, makes it clear that a radical reversal of ancestral ideas as to atmospheric evolution and early climatic history is upon us.

The admirable topographic work of Sargent furnishes an excellent basis for the stratigraphic mapping and the physiographic induction.

T. C. C.

Glaciers of the Canadian Rockies and Selkirks. By WILLIAM HITTELL SHERZER. Smithsonian Institution, 1907. Quarto, pp. 135.

This elegant volume gives the results of a systematic examination of the Victoria and Wenkchemna glaciers in Alberta and of the Yoho, Asulkan, and Illecillewaet glaciers in British Columbia. The study embraced the

surface features of these glaciers, the nature of the ice movement, the temperature of the ice at various depths and its relations to the air temperatures, the amount of surface melting, the possible transference of material from the surface portion to lower portions, the rates of movement, the advances and recessions of the glacial extremities, and the structure of the ice. There is an accessory discussion of the physiographic changes of the region in Pleistocene and earlier times.

The points that stand out most in the discussion are those which relate to the precipitation of snow and rain, the effects of climatic cycles on glacial movements, the stratification and granulation of the ice, its shearing planes, blue bands, and the possible methods of their development. A notable result is the demonstration by daily measurements of the shearing of layers of ice over one another, a phenomenon announced by Chamberlin as a result of his Greenland observations, but questioned by Russell and others. The conclusions relative to glacial movement lie essentially in the lines toward which the more critical recent studies by different investigators seem to be quite surely tending, a composite mode of motion embracing as factors of varying efficiency granular growth, granular intermovement, shearing of the sliding planes of the ice crystals, and shearing of the glacial layers over one another. An unsatisfactory flavor is given this by an effort, italicized as though important, to make plasticity mean something which plasticity does not usually mean, for no other apparent reason than to justify the retention of an old term which is likely to be either misleading or meaningless. The movement of the gliding planes of an ice crystal over one another is a plastic movement only in the forced sense that the sliding of cards in a pack, or of boards in a lumber pile, is a plastic movement, and such a movement is better called something else.

The work is very amply illustrated by excellent photographs and maps, and is an important contribution to glacial science.

T. C. C.

The Fauna of the Salem Limestone of Indiana. By E. R. Cumings, J. W. Beede, E. B. Branson, and Essie A. Smith. Thirteenth Annual Report of the Department of Geology and Natural Resources of Indiana, 1906. Pp. 1187–1487, 47 plates.

The Salem limestone of Indiana is known generally to geologists and business men as the Bedford limestone, receiving its name from the town at which are located so many of the large quarries of this formation; but the name was preoccupied when given to this limestone, since Bedford had

already been used by Dr. Newberry for one of the important formations of Ohio. Several years ago the Indiana formation was renamed the Salem limestone by Dr. Cumings from another town in the Indiana district where the formation is also well shown.

The introduction to the report, written by Doctors Cumings and Beede, gives an interesting account of the occurrence of this fauna as well as of the localities at which it is most abundant. This formation occurs, stratigraphically, near the base of the Mississippian series of Indiana, resting in the northern part of its outcrop on the basal limestone of the Indiana Mississippian—known as the Harrodsburg—and, in a large portion of its southern outcrop, upon a shale. The formation is said to be rather lenticular in its occurrence, pinching out at two known localities, attaining a thickness of fifty or sixty feet in the vicinity of Bedford where it is typically developed, oölitic or semi-oölitic in structure, and frequently cross-bedded. In their typical development the fossils are characterized by their stunted form and extreme abundance. The authors state that "the cross-bedding of the rock, its water-worn fossils, the fact that they are stunted, and the oölitic or semi-oölitic character of the rock, wherever typically developed, preclude the idea of its pelagic origin and argue forcibly in favor of a semi-littoral or lagoonal origin, as is also indicated by its broadly lenticular occurrence. . . . .

"In general the gastropods and brachiopods found in the Salem limestone are forms indicative of shallow conditions, such forms as might inhabit coral reefs and lagoons where there is considerable agitation of the water." This part of the report is illustrated by five half-tones giving views of characteristic exposures of the limestone and a sixth plate showing a slab of the fossiliferous limestone from Bloomington.

The greater part of the report, however, is devoted to a systematic description of the fossils of this limestone which are here, for the first time, brought together, described, and illustrated in one work. As might naturally be expected, it contains a description of a considerable number of new varieties and species, and it is stated that, "The larger part of the time was spent in the study of the corals, bryozoans, etc., not represented in the works of Hall and Whitfield." The descriptions of the Protozoa, Pentremites, Echinoderma, Vermes, Brachiopoda, and Pelecypoda are by Dr. Beede. Miss Essie A. Smith contributes an interesting paper on the "Development and Variation of *Pentremites conoideus*," in the closing part of which she discusses the "dwarfing of the fauna of the Salem limestone." Miss Smith states that this limestone "was probably laid down in a lagoon or partially enclosed sea, and the dwarfing of the fauna was perhaps due in

part to the smallness of the body of water and to an overcrowding." It is also noted that the increased number of poral pieces connected with the hydrospires, which are regarded as the respiratory organs of Pentremites, "would indicate an effort of the animal to adapt itself to a depletion of oxygen in this ancient sea."

The descriptions of the Bryozoa and Gastropoda including Crustacea are by Dr. Cumings. The Bryozoa come from the top of the formation in an exceedingly soft, loose-grained, and greatly decomposed limestone, in which they are beautifully preserved. It is stated that, "Very few Bryozoa have ever been described from the famous oölitic limestones of Indiana," and that, "No better preserved fossils have ever been studied by the writer than these exquisite Fenestellids and other Bryozoa from the Dark Hollow quarries of Bedford." The descriptions of the Vertebrates, which consist of fish remains, were prepared by Professor Branson, of Oberlin College. This portion of the monograph is illustrated by forty-two plates which in their reproduction leave something to be desired, as is frequently the case in the illustrations of the fossils contained in the reports of state geological surveys similar to that of Indiana.

C. S. P.

Evidences of a Coblenzian Invasion in the Devonic of Eastern America. By JOHN M. CLARKE. *Festschrift zum siebzigsten Geburtstage von Adolf v. Koenen*, pp. 359–68.

Dr. Clarke has devoted a portion of each of several recent summers to the field examination and collection of fossils of the Devonian formations of eastern Canada. In connection with this investigation he has critically studied the Devonian faunas of Gaspé in eastern Quebec, Dalhousie in northern New Brunswick, and those of the eastern and central portions of Maine, and this paper contains a preliminary statement of the results which have been obtained. It will be remembered that the Lower Devonian of central Europe has generally been divided into two terranes, of which the Gedinnian is the older and the Coblenzian the younger.

It is stated that in Gaspé the Lower Devonian faunas are singularly profuse and are contained in a series of limestones reaching an approximate thickness of 1,500 feet. These limestones rest unconformably on Cambrian slates and have been divided into three terranes. The lowest one has been called the St. Alban beds by Dr. Clarke and its fauna "is an almost pure strain of the Helderbergian (especially Coeymans limestone and New Scotland beds) of New York." The middle division is the Cape Bon Ami beds with a sparse fauna which, however, has a similar relationship to that

of the lowest beds. The top division is the Grande Grève limestone which is "the seat of a profuse fauna with very strong Oriskany traits commingled with features of still later age." The species indicating later age are stated to be such as might be paralleled with members of the Onondaga fauna of New York in an incipient stage of development, and present evidence of an earlier stage than that of the Onondaga. It is noted that certain species of this fauna occur in a very different facies than in New York since "the large, heavy-valved species of brachiopods which characterize the loose and coarse sandy deposits of the Oriskany in central New York here occur without diminution of size or essential change of structure in entirely pure limestone deposits," and *Hipparionyx proximus*, *Spirifer arenosus*, and *Rensselaeria ovoides* are mentioned as examples. It is stated that during Devonian time:

> The evidence is complete of an unimpeded passage and migration [from this region] southwestward into the Appalachian basin of New York and of entire isolation from any communication far enough to the east to register itself in the transatlantic faunas. The succession and trend of outcrops of all paleozoic formations from New York eastward to the Gulf of St. Lawrence, a distance of 600 miles, conveys the impression that the deposits in question were laid down in a relatively narrow channel bounded by Appalachian folds of the older land and this impression is fortified by the detailed study of this fauna and of the almost denuded patches of paleozoics lying in the region between.

At Dalhousie on the upper reaches of the Bay of Chaleur "is an isolated series of soft calcareous shales with interbedded contemporaneous effusives." Dr. Clarke states that he has determined about seventy species which may be used in comparison and correlation with other faunas. Nearly one-half of these are identical or affiliated with the Helderbergian fauna of the Appalachian gulf and a few of them are also present in the St. Alban beds of the Gaspé section. The pelecypod element shows a noticeable affinity with that of the Coblenzian, which is indicated by certain positive identifications as *Pterinea pseudolaevis* and *Carydium gregarium*. Only a few species of the brachiopods, however, can be referred to the European rather than the American type.

In Aroostook County in northeastern Maine are the Chapman sandstones which occur in two separate localities, one covering the upper reaches of Presqu'isle stream and the other known as Edmund's hill. The faunas of the two localities, however, show a decided difference since in a total of seventy-two probable species, forty-nine constitute the Edmund's hill fauna and twenty-five that of the Presqu'isle stream, while but two species are common to both outcrops. The two faunas, however, are united by

the affinities of each with the Coblenzian faunas with which they show the closest agreement, which consists of three identical species and twenty-seven affiliated ones, while the next nearest is with the Helderbergian and Oriskany of the Appalachian gulf with eight identical and thirteen affiliated species. Dr. Clarke concludes that "the inference is unavoidable that the predominating influence expressed in the Chapman congeries is that of the transatlantic faunas of contemporary age."

Again in Piscataquis and Somerset counties in northern and western Maine to the west of Aroostook County are beds of quite fossiliferous sandstone and sandy shale. This fauna comprises about seventy species, some of which are identical with members of the New York Oriskany fauna, as *Rensselaeria ovoides, Spirifer arenosus, Hipparionyx proximus, Rhipidomella musculosa* (var.), etc.; others which are not identifiable with known members of contemporaneous faunas; and finally a Coblenzian contingent, which enforces and supplements that appearing in Aroostook County.

As a result of these studies Dr. Clarke states in conclusion: "The evidence then is fairly conclusive that during the period represented by the Coblenzian-Oriskany the arenaceous epicontinental sediments were the ground traversed by the Coblenz fauna westward along the North Atlantic continent. . . . . The immigrant fauna taken as a whole is the direct descendant of the Coblenzian faunas, changed in part by variation and by mutation, and hence contemporary therewith only in the sense of being homotaxial; the lines of passage westward through the regions indicated in New Brunswick and Maine were courses of migration only, not basins of sequestration, fertile propagation, and dispersion as was the northern or Gaspé passage."

C. S. P.

Age of the Pre-Volcanic Auriferous Gravels in California. By J. S. DILLER. Proceedings Washington Academy of Sciences, Vol. VIII, pp. 405, 406. February 13, 1907.

The age of the auriferous gravels of the Sierra Nevada in California is generally given as late Miocene or Pliocene. This conclusion is based chiefly on fossil plants and a few animal forms. The auriferous gravel period in all probability was a long one and no considerable part of its flora has yet been connected directly with its contemporaneous marine fauna in the same region.

Mr. Diller has recently found a flora of ten species, determined by Dr. F. H. Knowlton, in beds that carry a large and definite Eocene marine fauna, studied by Dr. Wm. H. Dall. Three of these plants occur in the

auriferous gravels, indicating that the latter are, in part at least, Eocene. This discovery is important because the auriferous gravels have been relied upon in determining the age of the Sierra peneplain.

C. W. W.

The Drumlins of Southeastern Wisconsin. (Preliminary Paper.) By WILLIAM C. ALDEN. Pp. 46, 9 plates. Washington, D. C., 1905.

There are about 1,400 drumlins in this district, an area of some 4,200 square miles. The drumlins are distributed over the ground moraines of the Green Bay and Lake Michigan glaciers and have their longer axes in the direction of ice movement. They are all the product of the last ice invasion, at least so far as shaping is concerned. Over 90 per cent. of the drift in the drumlins of the Green Bay Glacier is of local derivation; about 9 per cent. must have been brought from the Canadian crystalline rocks.

C. W. W.